Claudia Gerling
Prehistoric Mobility and Diet in the West Eurasian Steppes 3500 to 300 BC

Topoi
Berlin Studies of the Ancient World

Edited by
Excellence Cluster Topoi

Volume 25

De Gruyter

Claudia Gerling

Prehistoric Mobility and Diet in the West Eurasian Steppes 3500 to 300 BC

An Isotopic Approach

De Gruyter

ISBN 978-3-11-030924-9
e-ISBN (PDF) 978-3-11-031121-1
e-ISBN (EPUB) 978-3-11-038838-1
ISSN 2191-5806

Library of Congress Cataloging-in-Publication Data

A CIP catalog record for this book has been applied for at the Library of Congress.

Bibliographic information published by the Deutsche Nationalbibliothek

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.dnb.de.

© 2015 Walter de Gruyter GmbH, Berlin/Boston

Cover image: © Merlin Flügel
Typesetting: Dörlemann Satz GmbH & Co. KG, Lemförde
Printing and binding: Hubert & Co. GmbH & Co. KG, Göttingen
∞ Printed on acid-free paper

Printed in Germany

www.degruyter.com

Table of Contents

Acknowledgements XI

1 Introduction 1

2 Background 7
2.1 Archaeological background 7
2.1.1 Introduction 7
2.1.2 The (Middle and) Late Eneolithic period in the North Pontic steppe . 7
2.1.2.1 History of Research 7
2.1.2.2 Characterisation of the (Middle and) Late Eneolithic steppe cultures 8
2.1.2.2.1 Chronology and regional subdivision 8
2.1.2.2.2 Economy and interaction of the Eneolithic steppe cultures 11
2.1.3 The Early Bronze Age Yamnaya period 12
2.1.3.1 Chronology 12
2.1.3.2 Distribution and regional subdivision 13
2.1.3.3 Burial tradition 15
2.1.3.4 Economy 16
2.1.3.5 Regional variants and distinct cultures of relevance 17
2.1.4 The Middle Bronze Age Catacomb culture period 19
2.1.4.1 Chronology 19
2.1.4.2 Distribution and regional subdivision 20
2.1.4.3 Burial tradition 21
2.1.4.4 Economy 24
2.1.5 (South)westward steppe impact 25
2.1.5.1 History of research 25
2.1.5.2 Late Eneolithic period 27
2.1.5.3 Early Bronze Age Yamnaya horizon 28
2.1.5.4 Middle Bronze Age Catacomb culture horizon 31
2.1.6 The Iron Age Scythian period 32
2.1.6.1 Introduction 32
2.1.6.2 Chronology and distribution of the Scythian cultural groups . 33
2.1.6.3 Historical sources of the Scythians 34
2.1.6.4 Characterization of the Scythian culture in respect to this study 35
2.1.6.5 Cultural groups touched upon in this study 37
2.2 Methodological background 41
2.2.1 The application of isotope analysis 41
2.2.1.1 Mobility in archaeology and the application of strontium and oxygen isotope analyses 42

2.2.1.2 Palaeodiet and the application of carbon and nitrogen isotope analysis . . . 44
2.2.2 Tooth and bone as sample materials and information archives . . . 46
2.2.3 Geology and ecology in the study region with regard to isotope analysis . . . 50

3 Sample sites and Material . . . 55
3.1 Introduction . . . 55
3.2 Eneolithic and Bronze Age . . . 56
3.2.1 Carpathian-Balkan region . . . 56
3.2.1.1 Bulgaria . . . 56
3.2.1.2 Hungary . . . 59
3.2.2 North Pontic region . . . 61
3.2.2.1 Central Ukraine . . . 61
3.2.2.2 East Ukraine . . . 64
3.2.3 Russia . . . 65
3.2.3.1 Volga region . . . 65
3.2.3.2 Kuban and Northwest Caspian Sea region . . . 67
3.3 Iron Age . . . 68
3.3.1 North Pontic region . . . 68
3.3.2 Central Asia: Berel' . . . 71

4 Mobility and Migration . . . 73
4.1 Introduction . . . 73
4.2 Theories on mobility and migration . . . 73
4.2.1 History of research in mobility and migration theories in prehistoric archaeology . . . 73
4.2.2 Mobility . . . 74
4.2.2.1 Definition . . . 74
4.2.2.2 Mobility models . . . 75
4.2.2.3 Characteristic forms of mobility in the Eurasian steppe belt . . . 77
4.2.3 Migration . . . 79
4.2.3.1 Definition . . . 79
4.2.3.2 Migration models . . . 79
4.2.3.3 Migration in the West Eurasian steppes . . . 81
4.2.4 Scientific contribution to mobility and migration research in archaeology . . . 82
4.3 $^{87}Sr/^{86}Sr$ analysis . . . 83
4.3.1 Basics . . . 83
4.3.1.1 Introduction . . . 83
4.3.1.2 Strontium in tooth and bone . . . 84
4.3.1.3 Definition of the 'local' biologically available strontium . . . 85
4.3.2 Material . . . 87
4.3.3 Methods . . . 88

4.3.3.1 Methodology for tooth enamel samples 88
4.3.3.2 Methodology for comparative samples 90
4.3.3.3 Strontium concentration measurements 91
4.3.4 Results 91
4.3.4.1 Correction of the $^{87}Sr/^{86}Sr$ isotope ratios 92
4.3.4.2 Results of the $^{87}Sr/^{86}Sr$ analysis 93
4.3.4.2.1 Eneolithic and Bronze Age 93
4.3.4.2.2 Iron Age 98
4.3.4.3 Intra-site and inter-site comparison 99
4.3.4.4 Inter-regional comparison 101
4.3.4.5 Differences related to gender and age 101
4.3.4.5.1 Eneolithic and Bronze Age 101
4.3.4.5.2 Iron Age 104
4.3.4.5.3 Comparison on a regional scale 104
4.3.4.6 Chronological differences 105
4.3.4.7 Strontium concentrations 107
4.3.5 Biological measurements of $^{87}Sr/^{86}Sr$ 110
4.3.5.1 Published $^{87}Sr/^{86}Sr$ data 110
4.3.5.2 Estimation of the 'local' $^{87}Sr/^{86}Sr$ range and identification of 'locals' and 'non-locals' 112
4.3.5.2.1 Eneolithic and Bronze Age 112
4.3.5.2.2 Iron Age 120
4.3.5.3 Evaluation of the 'local' $^{87}Sr/^{86}Sr$ values 122
4.4 $\delta^{18}O$ analysis 124
4.4.1 Basics 124
4.4.1.1 Introduction 124
4.4.1.2 Variations in $\delta^{18}O$ 125
4.4.1.2.1 General causes of variation 125
4.4.1.2.2 Seasonal variation 126
4.4.1.2.3 Intra-tooth and intra-species variation 127
4.4.1.2.4 Intra-site variation 127
4.4.1.3 $\delta^{18}O$ analysis of $\delta^{18}O$ in tooth enamel carbonate 129
4.4.1.4 Data conversion 129
4.4.1.4.1 Conversion of $\delta^{18}O_c$ measured against V-PDB into V-SMOW data 129
4.4.1.4.2 Conversion into data comparable to meteoric water . 130
4.4.1.5 Data comparison 133
4.4.1.5.1 Comparison to $\delta^{18}O$ results of studies in the same region 133
4.4.1.5.2 Comparison to $\delta^{18}O$ in modern precipitation . . . 134
4.4.2 Material 135
4.4.3 Method 135
4.4.4 Results $\delta^{18}O_c$ (V-PDB) 136
4.4.4.1 Eneolithic and Bronze Age 137

4.4.4.2 Iron Age 142
4.4.4.3 Intra-site and inter-site comparison 143
4.4.4.4 Inter-regional comparison 145
4.4.4.5 Gender and age related differences 145
4.4.4.5.1 Eneolithic and Bronze Age 145
4.4.4.5.2 Iron Age 149
4.4.4.5.3 Comparison on a regional scale 149
4.4.4.6 Chronological differences 150
4.4.5 Biological measurements of $\delta^{18}O$ 152
4.4.5.1 Estimation of the 'local' $\delta^{18}O$ range 152
4.4.5.2 Published data of $\delta^{18}O$ in humans and animals 152
4.4.5.3 Published modern water values 155
4.4.5.4 $\delta^{18}O$ in precipitation 155
4.4.5.5 Conversion of $\delta^{18}O$ in tooth enamel carbonate into $\delta^{18}O$ in water 158
4.4.6 'Locals' and 'non-locals' 159
4.4.6.1 Results of the data conversion into $\delta^{18}O$ in water and 'local' $\delta^{18}O$ ranges 159
4.4.6.1.1 Eneolithic and Bronze Age 159
4.4.6.1.2 Iron Age 164
4.4.6.2 Potential correlation between $\delta^{18}O$ results and longitude and latitude 165
4.4.6.3 Evaluation of the 'local' $\delta^{18}O$ values 166
4.5 Combined results and discussion of $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses 167
4.5.1 Eneolithic and Bronze Age 167
4.5.2 Iron Age 191
4.6 Discussion of this chapter's results 199
4.6.1 Sampling 199
4.6.1.1 Sample selection and sample size 199
4.6.1.2 Reference sample material and the definition of the 'local' signatures 200
4.6.1.3 Intra-individual sampling in humans 205
4.6.2 Identification of outliers 205
4.6.2.1 'Local' or 'non-local'? 205
4.6.2.2 Identification of outliers on an intra-site level 207
4.6.2.3 Identification of outliers on an intra-regional level 209
4.6.2.4 Identification of outliers on an inter-regional level 209
4.6.3 Reconstruction of economic systems 210
4.6.3.1 Mobility variants 210
4.6.3.2 Elements of uncertainty 212
4.6.4 Detection of a possible increase of mobility due to the emergence of draught animals, wagons and climatic changes using $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses 214
4.6.4.1 Site variability 214

4.6.4.2 Exceptional burials . . . 217
4.6.5 Mobility in the Iron Age Scythian period . . . 219
4.6.5.1 Human mobility . . . 219
4.6.5.2 Evidence for faunal mobility in the Iron Age Scythian period . . . 220
4.6.6 Isotopic indicators for possible migrations from the steppe area to the west . . . 221
4.7 Conclusions Chapter 4 . . . 223

5 Case study: Faunal mobility in the context of the Globular Amphora culture . . . 227
5.1 Introduction . . . 227
5.2 Theories of faunal mobility . . . 227
5.3 Stable isotope analysis of faunal mobility . . . 228
5.4 Archaeological framework . . . 229
5.4.1 Globular Amphora culture and cattle depositions . . . 229
5.4.2 Archaeology of Zauschwitz . . . 231
5.5 Expected isotopic values of Zauschwitz . . . 232
5.6 Material . . . 233
5.7 Results and discussion . . . 234
5.7.1 Strontium isotope analysis . . . 234
5.7.2 Oxygen isotope analysis . . . 235
5.7.3 Combination of strontium and oxygen isotope analyses . . . 237
5.8 Conclusions Chapter 5 . . . 240

6 Palaeodiet . . . 243
6.1 Introduction . . . 243
6.1.1 Objectives of this study . . . 243
6.1.2 Diet of the West Eurasian steppe people in the Eneolithic, the Early and Middle Bronze Age . . . 243
6.2 Methodological basics . . . 244
6.2.1 Potential information derived from stable isotope analysis . . . 244
6.2.2 $\delta^{13}C$ analysis . . . 245
6.2.2.1 Basic principles . . . 245
6.2.2.2 $\delta^{13}C$ in C_3 and C_4 plants and their consumers . . . 246
6.2.2.3 $\delta^{13}C$ in marine, freshwater and terrestrial diet . . . 246
6.2.2.4 Trophic level shifts . . . 247
6.2.3 $\delta^{15}N$ analysis . . . 248
6.2.3.1 Basic principles . . . 248
6.2.3.2 Trophic level effect . . . 249
6.2.3.3 Terrestrial, freshwater and marine food . . . 249
6.2.3.4 Climatic effect and water dependency . . . 250
6.3 Material . . . 250
6.4 Method . . . 251
6.5 Results of $\delta^{13}C$ and $\delta^{15}N$ analysis . . . 252
6.5.1 Sample preservation . . . 252

6.5.2 Results faunal material 252
6.5.3 Results human material 253
6.5.3.1 Human bones 253
6.5.3.2 Results and discussion of combined $\delta^{13}C$ and $\delta^{15}N$ analysis of the human bones 254
6.5.3.3 Human teeth 258
6.6 Discussion 258
6.6.1 Discussion of the results of the faunal references compared to further studies 258
6.6.2 Discussion of the results of the human bones 261
6.6.2.1 Internal site variation 261
6.6.2.2 Correlation between $\delta^{13}C$ and $\delta^{15}N$ ratios 263
6.6.2.3 Chronological comparison 266
6.6.2.4 Variations based on gender and age 267
6.6.3 Discussion of the results of human teeth 269
6.6.4 Discussion of possible dietary components 270
6.6.5 Comparison of the results for human bones to analogous studies . . 274
6.6.5.1 North Pontic region 274
6.6.5.2 Kuban region 276
6.6.5.3 West Pontic region 277
6.7 Conclusions Chapter 6 280

7 Summaries in English, German and Russian 283

8 Bibliography 295

Appendices
Introduction to the Appendices 327
Appendix A
I Sites 328
II Samples 349
Appendix B
Data $^{87}Sr/^{86}Sr$ analysis 384
Appendix C
Data $\delta^{18}O$ analysis 388
Appendix D
Data $\delta^{13}C$ and $\delta^{15}N$ analysis 399

Acknowledgements

It would not have been possible to complete this doctoral thesis without the help and support of a number of people.

Foremost, I am exceptionally grateful to my supervisors Prof. Dr. Dr. h.c. Wolfram Schier, Dr. Volker Heyd and Dr. Alistair Pike for advice, assistance and encouragement. I also thank Prof. Dr. Dr. h.c. mult. Hermann Parzinger for his assistance regarding the samples of the Scythian period. Furthermore, I would like to thank Dr. Elke Kaiser, Ivo Popov and Manfred Woidich of the Research Group A II of the Excellence Cluster 264 *Topoi* for fruitful discussions and sample acquisition. The award of a three years' doctoral grant by the Excellence Cluster *Topoi* facilitated excellent working conditions and extensive stays abroad.

I would like to give warm thanks to our cooperation partners from Bulgaria, Hungary, Kazakhstan, Russia and Ukraine for providing access to the samples and to their reports from the site and also for providing additional information:

- Dr. Daniela Agre, Dr. Stefan Aleksandrov (National Archaeological Institute with Museum, Bulgarian Academy of Sciences), Dr. Nadezhda Atanassova-Timeva, Borislava Galabova, Dr. Yordan Yordanov (Department of Anthropology and Human Anatomy, Institute of Experimental Morphology, Pathology and Anthropology with Museum, Bulgarian Academy of Sciences), Dr. Iliya Iliev (Museum of History Yambol), Dr. Plamen Karailiev (Archaeological Museum *Maritsa-Iztok*, Radnevo), Dr. Stefan Chohadzhiev (University of Veliko Tarnovo),
- Prof. Dr. Eszter Bánffy, Dr. Kitti Köhler, Dr. Gabriella Kulcsár (Institute of Archaeology, Hungarian Academy of Sciences, Budapest), Dr. János Dani (Déri Múzeum, Debrecen), Vajk Szeverényi (Móra Ferenc Múzeum, Szeged), whom I also thank for the close and excellent cooperation in writing two papers,
- Dr. Galiya Bazarbaeva, Dr. Zainolla Samashev (Academy of Science in Kazakhstan, Institute of Archaeology, Almaty),
- Dr. Aleksandr Gei (Russian Academy of Sciences), Dr. Aleksandr Khokhlov (Samarski State Pedagogical University, Samara), Dr. Natalya Shishlina (State Historical Museum Moscow) and her team at the excavation in Remontnoe,
- Dr. Marina Daragan, Dr. Aleksandra Kozak, Dr. Alla Nikolova, Dr. Inna Potekhina, Dr. Sergei Polin, Dr. Yuri Rassamakin (Institute of Archaeology, National Academy of Science in Ukraine, Kiev), Dr. Dimitrii Teslenko (University Dnepropetrovsk), Dr. Sergei Sanzharov (East Ukrainian Volodymyr Dahl National University Lugansk).

Sincere thanks are given to Dr. Elke Kaiser who travelled with me through the Ukrainian steppes in summer 2009 to collect reference sample material. The samples from one sites of the Globular Amphora Culture, located in Central Germany, were accessed with the help of Dr. Stefanie Bergemann, Norman Döhlert-Albani, Dr. Uwe Reuter, Thomas Reuter, Dr. Harald Stäuble, and Manfred Woidich.

I am extremely grateful to the group of researchers at Bristol University, the Bristol Isotope Group, especially to Dr. Christopher Coath and Prof. Dr. Tim Elliott, who gave me access to and assistance in their laboratories in the Department of Earth Sciences. Invaluable in the laboratories was the assistance and support of Dr. Riccardo Avanzinelli, Dr. Alistair Pike, Dr. Christopher Standish, Carolyn Taylor,

Hege Usborne and Dr. Jacqueline Wilson. Measurements of oxygen isotopes were done by Dr. Peter Ditchfield, of nitrogen and carbon by Prof. Dr. Robert Hedges and Dr. Erika Nitsch (RLAHA Oxford), who provided helpful additional advice. Generously, Dr. Annsofie Witkin identified the human teeth and Dr. Cornelia Becker and Prof. Dr. Norbert Benecke the faunal samples. Access to unpublished material was given by Dr. Robin Bendrey, Dr. Volker Heyd, Dr. Elke Kaiser, and Dr. Karen Privat.

Helpful discussions and comments came from Maik Blättermann, Prof. Dr. Jane Evans, Anton Gass, Dr. Andrea Gerling, Leon van Hoof, Dr. Hylke de Jong, Dr. Corina Knipper, Dr. Janet Montgomery, Prof. Dr. T. Douglas Price, Dr. Emily Schalk, Marlen Schlöffel, Rolf Seegelken, Barbara Sühs, Kai Sulkowski, Carolyn Taylor, János Tóth, Rouven Turck, and Ulrich Willenberg. For proofreading I am much obliged to Dr. Lucy Cramp, Nadine Freude, Dr. Elke Kaiser, Anne Kellner, Dr. Jessica Siller, Dr. Jenny di Leo, Tobias Nestmann, Dr. Erika Nitsch, Christine Schuh, Dr. Jane Seiter, Dr. Christopher Standish, Manfred Woidich, but most of all to Hege Usborne, who also did language corrections. Nataliia Chub translated the summary into Russian. Warm thanks are given to the editorial teams of *Topoi* and De Gruyter.

Finally, my gratitude goes to my family for their priceless support throughout my studies.

Berlin, August 2013

Postscript: This manuscript is a subtly revised version of my PhD thesis entitled 'Prehistoric mobility and palaeodiet in Western Eurasia. Stable isotope analysis of human populations and domesticated animals between 3500 and 300 BC', which was submitted in March 2012 and defended in July 2012. Relevant literature, which was published after this date, was added only exceptionally.

1 Introduction

Mobility, migration and subsistence strategies of past societies have always been of major importance in archaeological research, and this interest has a broader appeal now as 'The West' feels the combined effects of increased labour mobility, simplified mobility structures within the European Union and migrations from areas of conflict or poverty to countries with more stable political and economic systems.

The West Eurasian steppe, between about 3500 BC and 2000 BC, is particularly interesting in respect to past mobility behaviour. For almost one century, archaeologists have been trying to understand the lifestyle, subsistence economies and possible migrations of the late Eneolithic, the Early and Middle Bronze Age[1] Eurasian steppe communities. In spite of intense research and the discovery of important archaeological sites and finds, the picture remained unchanged and has only transformed in the last few decades to become 'one of the most dynamic fields in the whole ambit of prehistoric studies' (Renfrew, 2009, XVI). The second half of the 4th and the 3rd millennia BC are of particular interest, because a new extensive pastoral economy was accompanied by an unknown mobile economy and a new social organisation was introduced to the Eurasian steppes (Kristiansen/Larsson, 2005, 140). This time period is associated with a burial tradition that included the erection of burial mounds, called *kurgans* in Russian, in large parts of the West Eurasian steppes. This particular burial tradition, the paucity of archaeological evidence for permanent settlement sites and the widespread occurrence of similar cultural artefacts led many researchers to assume that the Early Bronze Age steppe communities were semi-nomadic[2] and pastoralist[3]. Animal bone assemblages in the few excavated settlement sites point towards a transition to a subsistence economy based on animal herding at the end of the 4th and the beginning of the 3rd millennia BC (cf. Černych et al., 1998, 244; Kaiser, 2012, fig. 83–85), indicating an economy based primarily on cattle with horses and sheep/goats playing minor roles (Kristiansen/Larsson, 2005, 173). This form of subsistence is often seen as only being effective when associated with circular mobility and pastoralism. Pastoral strategies 'contribute to a heightened degree of variation in mobility and subsistence strategy, in settlement ecology, and in commercial activity' (Frachetti, 2009, 41). An increased level of mobility might be represented in contemporaneous burial contexts including wheel and wagon burials. Early archaeological evidence of wheeled transport is associated with the northwest Pontic Tripolye culture, and the remains of wagons were frequently deposited in Yamnaya and Catacomb culture graves in the North Pontic and southern Russia (Kohl, 2002, 161; Kaiser, 2007; 2010). The concurrent appearance of similar traditions such as kurgans and other features of the burial ritual in the Carpathian-Balkan region led archaeologists to suggest the possibility of human migrations between the North Pontic regions and areas to the west of the distribution area. The early Iron Age in the steppes is tightly connected with the Scythians. In the 1st millennium BC, Scythian communities and groups that were culturally connected to them inhabited the Eurasian steppe belt. On the basis of

1 Following Russian terminology the Yamnaya culture belongs to an early and the Catacomb culture to a subsequent phase of the Bronze Age.

2 In this study 'Semi-nomadism' refers to a way of life that involves periodic, often extended, movements but also some settled component (for further discussion see Section 4.2.2).

3 'Pastoralism' is used to describe a subsistence pattern in which people live and move with their animal herds. It often involves a mobile herding strategy of domesticated animals, where movements depend on the availability of pastures and often follow seasonal and established cycles (for further discussion see Section 4.2.2).

archaeological and historical evidence, some of these communities are assumed to represent the first true nomads[4], not only living an unsettled lifestyle but also being involved in large-scale migrations.

The application of scientific methods to answer questions on mobility, possible migrations and dietary patterns has only entered archaeological research in the last few decades. In this study, questions of mobility and dietary patterns of the Eneolithic, the Early and Middle Bronze Age and the Iron Age societies in the West Eurasian steppes are addressed using multi-isotope analysis, namely $^{87}Sr/^{86}Sr$, $\delta^{18}O$, $\delta^{15}N$ and $\delta^{13}C$ analyses. Strontium isotope analysis enables the identification of human and faunal movements between various geological regions. In addition, oxygen isotope analysis is generally applied to reconstruct drinking water sources and identify the climatic environment that humans or animals inhabited due to the correlation of oxygen isotope ratios in skeletal tissue with local meteoric water. Both give valuable hints to small- and large-scale mobility of the prehistoric societies of West Eurasia. The analyses of carbon and nitrogen stable isotopes of skeletal collagen of the same humans help to classify their dietary backgrounds and to characterize the economy of the steppe communities. As a subproject of the research group A II 'Spatial effects of technological innovations and changing ways of life' within the Excellence Cluster *Topoi*, the present study can be distinguished from the majority of the huge range of recent stable isotope studies since it is the first large-scale investigation of mobility and subsistence patterns in an area that covers several thousand kilometres and several chronological periods. Running a study of this scale is only possible against the financial background of a research cluster such as *Topoi*. Other studies, however, focus on single sites which enables the reconstruction of the surrounding areas of usage to answer the questions raised above. The combined effect of a number of factors made the interpretation of the analyses more challenging than for some single site studies. These factors include the fact that the number of samples available per site in each age range was often small, that comparative data was sometimes inadequate, that few other studies have been undertaken for these time periods in these areas, and most crucially that the application of stable isotope analysis to mobile communities with unknown places of residence is fraught with difficulties. Nevertheless, this doctoral thesis forms the first step in expanding the biogeochemical data set from the West Eurasian steppes and breaks new ground by applying a combination of different isotopic systems to an area of vast chronological and spatial dimensions. The main objectives are as follows: 1) Characterise the mobility and subsistence patterns of the archaeological communities under discussion, 2) identify potential Early Bronze Age migrations from the West Eurasian steppes to the steppe-like plains in parts of Eastern Europe, and 3) evaluate the applicability of stable isotope analyses in this context.

The study focuses on the West Eurasian steppes, namely the North Pontic steppe and its adjacent areas. The ecological region of the West Eurasian steppe expands from the plains in southeast Europe at its westernmost part, to the Ural Mountains in the east. The North Pontic steppes extend approximately 1000 km in an east-west direction and 500 km from north to south. They are principally located in the southern part of present-day Ukraine, bounded by the semi-deserts towards the coasts of the Black Sea and the Azov Sea in the South. The Danube River defines the western border, while the lower Don River limits the area to the east and the forest-steppes border to the north (Kremenetski, 2003, 11).

4 In this study, the term 'Nomadism' refers to a lifestyle where mobility provides the most efficient adaptation to exploit resources in a specific, often infertile, landscape (cf. Stasevič, 2013, 19–25 citing Марков, 1973, 101–113; Масанов, 2001, 84; for further discussion see Section 4.2.2).

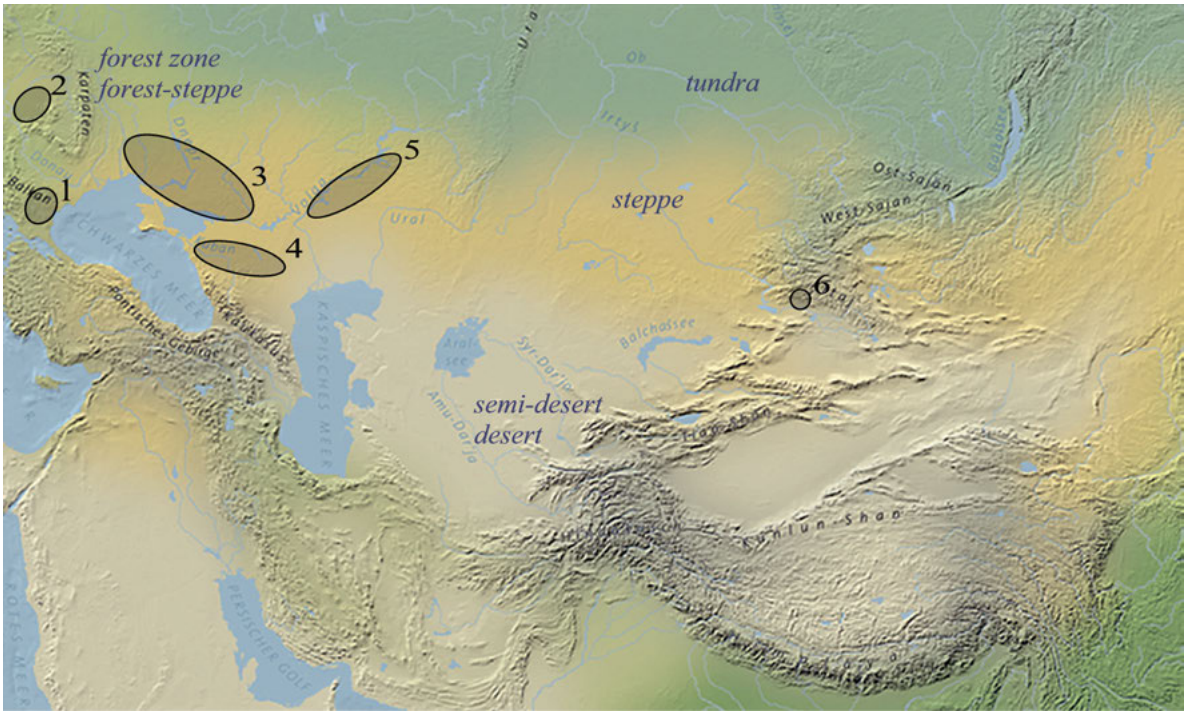


Fig. 1.1 | Micro regions and single sites selected for multi-isotope analysis in respect to vegetation zones (underlying map © D. Bordon).

Within this vast area of West Eurasia, multiple sites or micro regions[5] have been selected at random for isotopic analysis. All of them are located in the steppe, at the border to the forest-steppe or in deciduous hardwood forest. Figure 1.1 shows the Eneolithic, Early and Middle Bronze Age sites in modern Bulgaria (1), Hungary (2), the North Pontic/Ukraine (3), southern Russia, including one site in the Kuban region and one site in the northwest Caspian steppes (4), and at the Volga River (5). In addition, several sites in the context of the Scythian period, in the North Pontic region (3) and the Altai Mountains (6) were chosen for isotope analysis.

The study addresses the Late Eneolithic and the Early and Middle Bronze Age, which equates roughly to the time between 3500 BC and 2000 BC (Table 1.1) when the North Pontic steppes and adjacent areas were predominantly inhabited by groups of the Yamnaya culture (late 4th to middle 3rd millennium BC) and the partly overlapping and subsequent Early and Developed Catacomb culture (early to late 3rd millennium BC). During this time, and principally during the period of the Yamnaya culture, different aspects of the burial traditions of cultures inhabiting parts of the East European lowlands suggest a cultural influence from the steppes. Samples from a number of Scythian sites dating to the second half of the 1st millennium BC were selected for the sake of comparison.

Chapter 1 introduces the study and its principle objectives and summarises its integrated approach geographically and chronologically. Chapter 2 provides the background information relevant to this

5 The term 'micro region' will be used equivalent to 'region' to describe small to medium spatial units of geographic or cultural similarities regardless of the common use of this term in a modern political sense (cf. Roth, 2007, 18–19).

Table 1.1 | Simplified chronological overview of the second half of the 4th millennium and the 3rd millennium BC in the North Pontic and its adjacent areas (modified after Rassamakin, 1999, 77 table 3.2; Kaiser, 2005, 267 table 1).

BC	Northwest Pontic	North Pontic	Kuban, Precaucasus	Lower and Middle Volga
2000				
	Developed Catacomb culture (Ingul variant)	Developed Catacomb culture (local variants)	Developed Catacomb culture (Precaucasus variant)	Poltavka culture
2500	Yamnaya culture	Early Catacomb culture Yamnaya culture	Early Catacomb culture Yamnaya culture	
		Yamnaya culture	Yamnaya culture Novotitarovskaya culture	
3000	Usatovo culture	Late Eneolithic steppe cultures	Maikop-Novosvobodnaya culture	Repin culture
3500				

study. Section 2.1 focuses on the prehistoric archaeology of the West Eurasian steppes during the 4th and 3rd millennia BC and the Iron Age Scythian period. The overview of the archaeological cultures examined in this study includes the history of research and the most important features in respect to this investigation. The methodological background of isotope analysis as a tool to identify mobility and dietary habits is introduced in section 2.2. This consists of the research history of the application of isotope analysis in archaeology, a short introduction to the geological and ecological conditions of the study area, followed by a discussion of human and faunal tissue as sample materials. Chapter 3 is dedicated to the introduction of the study area and sample sites. The description of the study sites and the sample material is arranged in a chronological and geographical order. A brief introduction to the respective regional geology is followed by an explanation of the sampling strategy and sample selection, including archaeological and anthropological background information on the samples selected for analysis. Chapter 4 expands on the issue of mobility and migration. First, the current state of research, relevant theories and models and their significance for the study area are discussed (Section 4.2). Secondly, the methods used to investigate these questions, strontium (Section 4.3) and oxygen (Section 4.4) isotope analyses, are introduced. Both subchapters are divided into the following sections: The discussion of the basics of the methods is followed by the introduction of the selected sample material and complemented by the analytical protocols. The presentation of the results is complemented by the definition and discussion of samples that are consistent with 'local' and 'non-local'. Section 4.5 then presents the combined results of strontium and oxygen isotope analysis and a more detailed discussion on 'local' and 'non-local' sampled individuals. Finally, Section 4.6 provides the synthesis and the conclusion of the $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses in respect to the objectives of the study. Following this chapter, which mainly focuses on human mobility, the issue of faunal migration will be touched on in a case study using the example of a Globular Amphora cattle deposition in Zauschwitz, Germany (Chapter 5). Chapter 6 focuses on the investigation of possible dietary patterns of the Eneolithic, Early and Middle Bronze Age societies in the study area using carbon and nitrogen isotope analysis. This study is presented separately due to marginally differing data bases. The introduction of the methodological basics (Section 6.2) and the sample material deriving from several exemplarily selected sites in the North, the West Pontic and

the Kuban region (Section 6.3) is followed by the description of the analytical protocol (Section 6.4) and the presentation (Section 6.5) and discussion (Section 6.6) of the analytical data. Chapter 7 summarises the key conclusions that have been drawn throughout the course of this study. Furthermore, the applicability of the stable isotope analyses in the study area is evaluated and an outlook is given on possible future research. Finally, a conclusion of this study's main results is given in German and Russian.

2 Background

2.1 Archaeological background

2.1.1 Introduction

The sample material for the present study derives from cultures of the Middle[1] and Late Eneolithic, the Early and Middle Bronze Age[2] and the Iron Age. These cultural entities will be characterised briefly below.

2.1.2 The (Middle and) Late Eneolithic period in the North Pontic steppe

2.1.2.1 History of research

Research into the Eneolithic period in the North Pontic region has concentrated mainly on the resident Tripolye culture, which was located in the northwest Pontic forest-steppe zone (for an overview of the research history of the Tripolye culture see Dergačev, 1991, 3–6). Since the 1950s, however, the Eneolithic cultures in the West Eurasian steppe zone have also caught the attention of researchers. The history of research into the cultures that were present in the North Pontic steppes during the Eneolithic has been extensively described by Y. Ya. Rassamakin (1999, 59–67; 2004, 1–12) and therefore need only to be summarized at this point. In 1929 V. G. Childe first suggested that 'nomad invaders from the east introduced the copper battle-axe' and erected the first burial mounds in the areas to the west of the East European steppe cultures (Childe, 1929, 207). Some decades later, M. Gimbutas coined the term 'kurgan culture' and established a model of three successive waves of Eneolithic and Early Bronze Age steppe cultures that migrated westward and overran the agricultural societies in the Carpathian-Balkan region (Gimbutas, 1956, 70–71, cf. Chapter 2.1.5). Gimbutas assigned two of her 'kurgan waves' to the Eneolithic period. She regarded the Eneolithic Sredny Stog II culture as originating in the Volga region and as having migrated into the North Pontic region in a first kurgan wave, dating to approximately 4400 to 4200 BC. According to her warlike steppe communities subsequently moved to the Carpathian-Balkan region and the Caucasus. In a second kurgan migration wave, dating to the advanced Eneolithic period, between 3400 and 3300 BC, Gimbutas included the Mikhailovka I and Maikop groups (Gimbutas, 1994, 21–48; 89–122; see also Gimbutas, 1977; 1979). In the middle of the 20th century, a number of Russian-speaking archaeologists, namely V. N. Danilenko (Даниленко, 1955; 1974), N. Ya. Merpert (first Мерперт, 1959) and D. Ya. Telegin (first Телегин, 1966), started to focus on the East European steppe cultures and published several models in order to enable their regional and chronological sub-

1 Some analysed burials in the North Pontic region date to the Middle Eneolithic: Vinogradnoe kurgan 24, burial 30, Peshtchanka group 2, mound 1, burials 6, 7 and 14 (Rassamakin, 2011, 304 table 3). Most graves of the Eneolithic cemetery of Smyadovo date to the 5th millennium BP.

2 The first important cultural entity of the Bronze Age in the West Eurasian steppes is the Yamnaya culture, the second being the Catacomb culture. According to Russian terminology the Yamnaya Culture dates to the Early Bronze Age, while the Catacomb Culture counts to the Middle Bronze Age. The question of whether the Yamnaya and Catacomb cultures are in fact cultures, cultural entities or synonyms for common burial traditions shared by distinct smaller cultures is still under debate.

division. Telegin outlined a chronology of the Sredny Stog culture and established a cultural sequence of Kvityana, Sredny Stog II and Dereivka, which is basically similar to Danilenko's subdivision. Some decades later, in the 1980s, O. G. Shaposhnikova (Шапошникова, 1985; 1987) proposed a chronology that drew on both the Danilenko and Telegin models, and in 1985 I. B. Vasilev and A. T. Sinyuk (Васильев/Синюк, 1985) presented a cultural-chronological overview of the Eneolithic in the forest-steppes of the Middle Don and the steppes and forest-steppes of the Volga region (cf. Rassmakin, 1999, 62–67 for references in Russian). Dismissing these former models as too simple and 'not reliable' (Rassamakin, 1999, 72), Y. Ya. Rassamakin published a new classification of the Eneolithic burials between the Danube and the Don region (Rassamakin, 1999; 2004), in which he proposed a large variety of cultural groups with differences in chronology and regional distribution.

2.1.2.2 Characterisation of the (Middle and) Late Eneolithic steppe cultures

2.1.2.2.1 Chronology and regional subdivision

According to Rassamakin, the Eneolithic in the North Pontic region can be subdivided into three successive periods with the Middle Eneolithic from 3900/3800 to 3500/3400 cal BC and the Late and Final Eneolithic starting around 3500/3400 cal BC and ending approximately 3000/2900 cal BC (Table 2.1) (Rassamakin, 1999, 97, 129; 2011b, 294 table 1). Since this project is limited to the middle, late and final period of the Eneolithic, only these periods will be characterised in further detail. Y. Ya. Rassamakin sorted the confusing mosaic of archaeological cultures that were assumed to exist during the Eneolithic period and published a summary of those in the area between the Don and the Danube (Rassamakin, 1999; 2004), where he distinguished between four distinct Eneolithic burial traditions, according to skeletal positioning, that emerged in the Middle Eneolithic period. In a second step, he was able to assign these burial traditions to different cultures. According to Rassamakin (1999, 73; 2004, 141–142, fig. 111; 2011b, 298), burial tradition I is characterized by extended supine burials underneath burial mounds. In burial tradition II skeletons are buried in supine positions with varying flexed leg positions typically arranged in flat cemeteries but also underneath burial mounds. The burials of tradition III are characteristically crouched on the side either with both arms extended towards the knees or one arm extended and the second one bent. Strongly crouched positions on the side with arms intensely bent and hands in front of the face represent a variation and correspond to the forth burial tradition.

Using a combination of burial traditions and certain ceramic assemblages, Rassamakin was further able to connect these burial traditions with cultural groups, namely the Kvityana culture (1st burial tradition), the late Post-Stog group (2nd tradition) and the Lower Mikhailovka culture (3rd burial tradition). The fourth burial tradition occurred only in the Late Eneolithic (Rassamakin, 1999, 75–97; 2004, 185–209; 2011b, 299).

According to Rassamakin (1999, fig. 3.2a), new cultures emerged due to the relationship between different economic systems and their adaptations to changing environmental conditions in the Middle Eneolithic during the first half of the 4th millennium BC. The rather uniform Cucuteni-Tripolye complex, distributed in the forest-steppe between the Carpathian Mountains and the Dnieper River and then in its B2/C1 phases, continued to border the North Pontic steppe cultures to the west. In contrast, numerous new cultural groups emerged in the steppe zone to the east and the south arising from the preceding Skelya culture. These were the Lower Mikhailovka, the Kvityana and the Dereivka cultures

Table 2.1 | Periodisation of the Eneolithic period in the North Pontic steppes (modified after Rassamakin, 1999, 77 table 3.2; Rassamakin, 2011, 294 table 1).

Period	cal BC	Cultural features
Early Eneolithic	**4750(?) – 4200/4100**	Skelya culture
Steppe 'hiatus'	**4200/4100 – 3900/3800**	Sredny Stog II type
		Igren' VIII type (both in the Dnieper area)
Middle Eneolithic	**3900/3800 – 3500/3400**	Lower Mikhailovka culture
		Kvityana culture
		Post-Stog groups
Late Eneolithic	**3500/3400 – 3000/2900**	different local groups in the steppe area
		Repin culture
		Usatovo culture (NW Pontic)
		Zhivotilovo-Volchanskoe group
		Maikop-Novosvobodnaya (Kuban region)

along the Dnieper, the Repin culture in the forest-steppe zone on the middle Don and the Konstantinovka culture further south in the lower Don and the Azov steppe regions. To the south this variety of steppe cultures was bordered by another important cultural complex, the Maikop-Novosvobodnaya culture, in the Kuban and northern Caucasus region (Rassamakin, 1999, 87, 114–122). According to Rassamakin (2011b, 303), the steppe cultures during this period were dependent on two settled communities: the Tripolye culture in the west and the Maikop-Novosvobodnaya culture in the south.

The process of cultural changes continued into the Late and Final Eneolithic period, until the large cultural entity of the Cucuteni-Tripolye complex collapsed at the end of the Eneolithic, and can be regarded as a 'shift from a more sedentary to a more mobile way of life or [...] agriculturalists are becoming pastoralists' (Kohl, 2002, 160). Besides the destruction of the settled structures by nomadic steppe people (cf. Lichardus, 1988; Lichardus/Lichardus-Itten, 1998), additional reasons like climatic change and the discovery and exploitation of new copper ore sources are suggested as potential causes for the breakdown of the Cucuteni-Tripolye complex into numerous regional post-Tripolye groups (Kohl, 2002, 157–158). The Gorodsk, Sofievka, Gordineshti/Kasperovka and the Vykhvatinsky were the new cultural groups that emerged from the preceding cultural complex (Fig. 2.1). The Usatovo culture was located to the south of these regional groups between the rivers Dniester and Lower Danube on the northwest Pontic coast. Finds from burial mounds and settlements show the influence of various cultures and a combination of elements from the steppe cultures and the Cucuteni-Tripolye traditions, while the copper work shows links with the Balkans (Chernykh, 1992, 95; Kaiser, 2012, 10). Significant features of this cultural entity within a period of cultural transformation are an 'agro-pastoral' and sheep based economy (Rassamakin, 1999, 149), the erection of burial mounds that, according to Rassamakin (2011b, 303), count as the 'most significant examples of the early ritual stone architecture of the steppes' and an important role in the transfer of arsenic copper (Govedarica/Manzura, 2011; Kaiser 2012, 10).

Rassamakin suggests that two migrations at the end of the Eneolithic period had a determining influence on the formation of the Early Bronze Age Yamnaya culture (Rassamakin, 1999, 124, fig. 3.49). The first is evidenced by the Zhivotilovo-Volchanskoe-type burials at the end of the Eneolithic period, regarded as a link between the two large cultures of Tripolye and Maikop due to the combination of elements from both burial traditions. Furthermore, this cultural group is regarded as being associated

Fig. 2.1 | Distribution of cultures of the North Pontic in the later Eneolithic (modified after Rassamakin, 1999, fig. 3.3; Dergačev, 1991, 2, underlying map © D. Bordon). Samples dating to the Eneolithic period were obtained from: 1 Smyadovo, 2 Sárrétudvari, 3 Peshtchanka, 4 Vinogradnoe.

with migrations and in this context with the transmission of early wheeled transport (Rassamakin, 1999, 92–97, 123; Kaiser, 2012, 13). The second is the dispersal of the Repin culture, formed in the middle Eneolithic in the middle Don region, to the south, southeast and southwest (Rassamakin, 1999, 125). According to Rassamakin, the Dereivka culture stayed to the north of the Kvityana culture, and the Repin and the Konstantinovka cultures were still evident at the river Don. Besides these new developments, several cultural groups remained from the preceding period, namely the Dereivka, Kvityana and Lower Mikhailovka along the Dnieper and the Repin and Konstantinovka culture along the Don. The Lower Mikhailovka culture was located in the southern North Pontic steppes between the Danube and the river Molochnaya. Characteristically for this culture, burials were crouched on the side, together with a specific type of pottery in oval-shaped burial pits (Fig. 2.2: 3, 4), though skeletons were occasionally placed in crouched or extended supine positions. The burial pits were covered by low mounds, sometimes surrounded by ditches and stone circles, for which the term *cromlech* was adopted. Occasionally, stone stelae occur (Mallory, 1989, 203; Rassamakin, 1999, 91–92; Anthony, 2007, 270). The Kvityana culture (or Post-Mariupol culture according to Anthony, 2007, 271), located further north, in the regions of the Dnieper, the Severskii Donets and the Azov region, is another culture persisting from the preceding period. Supine inhumations in rectangular pits, frequently lined with stone and covered with stone slabs or wooden beams, are characteristic for this culture (Fig. 2.2: 1, 2). The graves are covered by low burial mounds, which are occasionally surrounded by stone circles. Red ochre colour and burial objects such as pottery of the Kvityana type, statuettes, stone hammer heads and bone or, less frequently, copper beads or ornaments are typical (Rassamakin, 1999, 83–87; Nikolova, 2006a, 5–11; Anthony, 2007, 271).

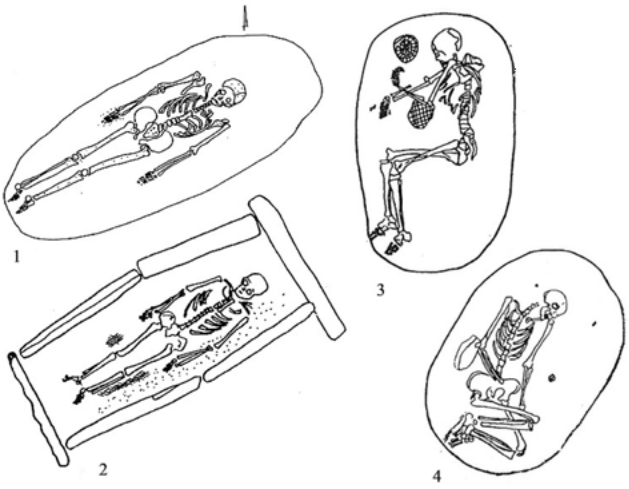


Fig. 2.2 | Eneolithic burials of the Kvityana culture (1 Kamenka-Dniprovskaya, kurgan 8 grave 13;2 Marevka, kurgan 14 grave 7) and the Lower Mikhailovka culture (3 Balki 'Vysokaya Mogila' grave 7; 4 Kovalevka 7, kurgan 4 grave 32) (after Rassamakin, 1999, fig. 3.19, 3.25).

The monumental burial architecture of the steppes emerges in this period as a direct consequence of the cultural system of the Middle Eneolithic (Rassamakin, 1999, 122–125; Rassamakin, 2011, 299). The earliest burial mounds are found in the North Pontic region and date to as long ago as the Early Eneolithic period in the 5th millennium BC, when the first elite burials in simple pits, stone cists and catacomb constructions were covered by shallow natural mounds (Rassamakin, 2011, 294–298). Rassamakin holds the opinion that the development of this first steppe monumental architecture was influenced by connections with both the Balkan-Carpathian metallurgical province and the North Caucasian Pre-Maikop cultural system (Rassamakin, 1999, 97–112; 2011b, 296). Govedarica (2010, 5–6) considers the burials of the second half of the 5th millennium BC as the beginning of the steppe kurgan tradition. According to A. V. Nikolova (2006a, 5 comments 1, 12), however, the erection of kurgans starts as early as the Early Eneolithic, though it is only in the Late and Final Eneolithic that they appear regularly. According to Rassamakin, the burials of the middle and late Eneolithic steppe cultures, featured by burials in pits, stone and wooden cists, covered by mounds of soil and clay and surrounded by ditches, stone circles and cromlechs as well as ritual elements like fire places and offering pits, illustrate the first ritual monumental architecture that set the starting point of the kurgan tradition (2011b, 294 table 1, 299). Burial mounds of this period are known from the Lower Mikhailovka and the Kvityana and Konstantinovka culture (Kaiser, 2012, 15), dating to the first half and mid 4th millennium BC.

2.1.2.2.2 Economy and interaction of the Eneolithic steppe cultures

Several scholars have attempted to characterise the Early Bronze Age steppe economy, mainly describing it as nomadic, semi-nomadic or seasonal pastoralist, while the economy of the Eneolithic period is thought to have included settled components. According to Rassamakin (1999, 129–130), the debate is currently unresolved, and 'the precise nature of the economic systems of the Pontic steppe tribes remains unknown'. Although relatively few settlements are known from the Middle and Late Eneolithic period, those that have been found are distributed across most parts of the East European steppes (Rassamakin, 2004, 197–203) and are characterised by varying economic systems adapted to local conditions (Rassamakin, 1999, 147–151). There is archaeological evidence for farming activities in the Dereivka culture, but

it also appears that hunting and herding were of increased importance in the forest-steppe zone. Animal husbandry, particularly of sheep or goats, also formed the basics of the economy of the Lower Mikhailovka culture in the steppe zone (Rassamakin, 1999, 147–149) and Anthony cites evidence of crop-cultivation in the form of grain imprints on pottery fragments[3] (Anthony, 2007, 269; cf. also Rassamakin, 1999, 147). As mentioned above, there is archaeozoological evidence that sheep breeding also formed the economic basis of the Usatovo culture in the northwest Pontic region (Rassamakin, 1999, 149).

According to K. P. Bunyatyan (2003, 272) a new economic system based on mobile stockbreeding was developed in the Northern Pontic steppes during the Eneolithic. Rassamakin also holds the opinion that in the Final Eneolithic the agricultural economic systems collapsed and were replaced by various forms of mobile pastoralism, spurred on by the emergence of wheeled transport, indicated by wooden wheels first occurring in burials at the Lower Don and in the Kuban region (Rassamakin, 1999, 149–151). It is probable that these changes are connected with the steppes, and are apparent in imported pottery and the exchange of prestigious metal objects between the steppe belt and Eastern Europe (Heyd, 2012). Anthony holds the opinion that two interaction spheres can be seen between steppe and neighbouring cultures. While the western steppe groups interacted with the Cucuteni-Tripolye culture, the southern groups were interconnected with the Maikop culture (Anthony, 2007, 267), which subsisted on stockbreeding and to a minor extent on agriculture. Korenevskii referred to the Maikop culture as 'mobile-settled farmers and stockbreeders' (Кореневский, 2004, 73–76 cited in Kaiser, 2012, 14).

2.1.3 The Early Bronze Age Yamnaya period

2.1.3.1 Chronology

The Yamnaya cultural groups can be dated to the 3rd millennium BC and are commonly regarded as the first Bronze Age culture in the West Eurasian steppe belt. The division of the Bronze Age goes back to V. A. Gorodtsov (Городцов, 1905; 1907), who distinguished between three Bronze Age phases based on his observations of burial traditions in the Severskii Don region (Kohl, 2007, 128), namely the Pit Grave culture (Yamnaya), the Catacomb culture (Katakombnaya) and the Timber Grave culture (Srubnaya).[4] The name 'Yamnaya culture' derives from the Russian term *yama*, which means pit. It is therefore also referred to as 'Pit Grave culture' or in earlier studies as 'Ochre Grave culture' (based on Häusler, 1974; 1976; the Yamnaya culture is referred to as the older phase of the ochre graves, while the subsequent Catacomb culture is referred to as the younger phase). Furthermore, the Yamnaya culture is connected to the fourth phase of M. Gimbutas' model of 'kurgan cultures', in which she included all late Eneolithic and Early Bronze Age cultures burying their dead in burial mounds (Gimbutas, 1979).

Anthony (2007, 272, 306) suggests the date of the Yamnaya culture in the North Pontic region to be the period between roughly 3300 BC (including Repin as an early phase of the Yamnaya culture) to the third quarter of the 3rd millennium BC. Further publications propose time spans between 3000/2900 BC and 2300/2200 BC [Rassamakin 1999, 125; radiocarbon dates suggest time-spans from

3 The evidence for agricultural activities for the Eneolithic and Bronze Age in the relevant geographic regions is heavily disputed (e.g. Anthony et al., 2006, 408–409 in respect to Late Bronze Age Srubnaya sites in the Samara valley region); cf. also Chapter 5.

4 Names for Early Bronze Age cultures and regional groups or variations vary (cf. Kohl, 2007, 129).

2900 to 2300 cal BC on wood and 2800 to 2380 cal BC on bone respectively (Rassamakin/Nikolova, 2008, 67)], 3300/3200 to 2100/2000 cal BC, based on a set of 210 ^{14}C dates (Telegin et al,. 2003, 150, 132–184) or approximately 3200 to 2400/2300 cal BC (Shishlina, 2004, 101 for the northwest Caspian region).

O. A. Krivcova-Grakova found a time-related trend from supine flexed burials to crouched burials on the side based on stratigraphic observations in a kurgan group near the modern town of Nikopol' (Nikolova, 2006b, 24 citing Кривцова-Гракова, 1962, 7), and subsequently N. Ya. Merpert was able to subdivide the Yamnaya culture into three phases through the differentiation of burial traditions in relation to stratigraphical observations in the Volga-Ural region (cf. Kaiser, 2012, 17–18 citing Мерперт, 1974, 54–69). These observations were later supplemented by the results of A. V. Nikolova, who undertook investigations in the Yamnaya distribution area of modern Ukraine.[5] On the basis of a statistical analysis of more than 2000 burial complexes Nikolova was able to differentiate eight temporal horizons that can be assigned to three chronologically distinct phases (Kaiser, 2012, 19–20 citing Николова, 1992) using the following criteria: the position of the grave within the mound, the shape of the burial pit, the position and orientation of the skeleton and the ochre colouring (Nikolova, 2006b, 25). The first phase is only present in some regions and is characterised by intensive kurgan building, supine crouched burials, east-west head orientation and ochre colouring. While supine flexed burials are still predominant in the second phase, orientation changes to the west and pre-existing mounds are utilised. The first crouched burials on the side, oriented to the east, occur in this phase and the Yamnaya culture is also more widely spread. The third phase is characterised by gradually changing burial traditions. Burials become predominantly positioned on the side, orientations of the skeletons vary and the position of the burial in the kurgan is inconsistent. While the number of burials increases from the first to the third phase, the use of ochre colouring decreases and the addition of hammer-headed pins is typical in this phase (Nikolova, 2006b, 25–28). An overall internal chronology does not exist, since further research has mainly either been restricted to limited regions, or referred to as variants, groups or even cultures, and thus has not been transferable to the complete distribution area of the Yamnaya culture (Anthony, 1986, 297; Rassamakin/Nikolova, 2008, 52; Kaiser, 2012, 19).

2.1.3.2 Distribution and regional subdivision

The consistency of burial tradition is the uniting element of the Yamnaya culture and its distribution area covers most of the West Eurasian steppes from the Lower Danube and the Carpathians in the west to the southern Urals in the east with single graves occurring even southeast of the Ural Mountains (Anthony, 1986, 298; Koryakova/Epimakhov, 2007, 45–54; Rassamakin/Nikolova, 2008, 51).

Although common burial traditions are distributed over a vast territory of the steppe belt, the Yamnaya culture is certainly no homogeneous cultural entity but a 'cultural and historical intercommunity' (Koryakova/Epimakhov, 2007, 46) and can be subdivided into a number of regional variants. N. Ya. Merpert recognised in 1974 that the origins of the Yamnaya culture could be found on the steppes between the rivers Don and Volga (Anthony, 1986, 297), where the Yamnaya characteristics probably developed from the Eneolithic steppe populations, namely the Repin and the Khvalynsk cultures (Anthony, 2007, 275), but this is still debated (Nikolova, 2006b, 23). Y. Ya. Rassamakin, for example, does not consider

5 Nikolova's observations for the Lower Dnieper region were published in Nikolova, 2006b.

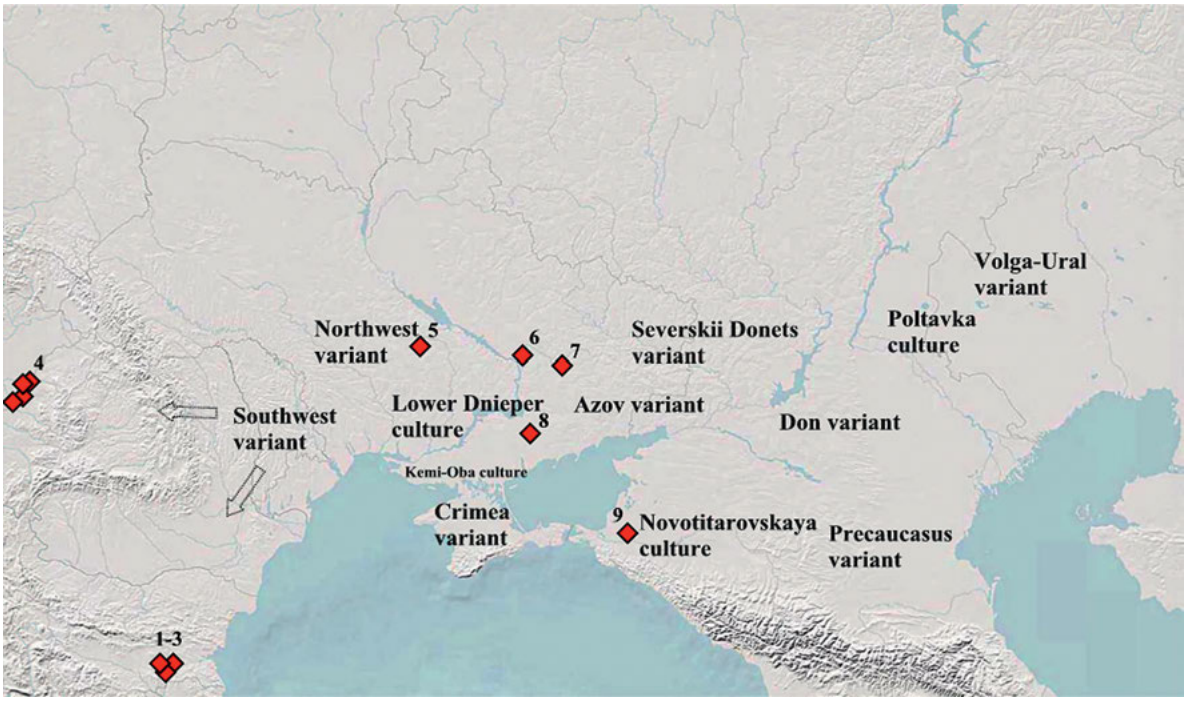


Fig. 2.3 | Distribution of the regional variants of the Yamnaya culture (based on Мерперт, 1974; modified after Kaiser, 2012, 17 fig. 4; underlying map © D. Bordon). Samples were selected from the following Early Bronze Age sites: 1–3 Benkovski, Boyanovo, Ovchartsi, 4 sites in Hungary, 5 Kirovograd, 6 Peshtchanka, 7 Shakhta Stepnaya, 8 Vinogradnoe, 9 Olennii (Novotitarovskaya culture).

the Repin culture to be an early phase of the Yamnaya culture (Rassamakin, 1999, 124). The Yamnaya culture in its early phase had a relatively uniform appearance and regional variants are mainly distinguishable in the later phase, when the Yamnaya distribution area was significantly extended towards the forest-steppe, deep into the Carpathian-Balkans region and further to the east (Parzinger, 1998, 467–468). N. Ya. Merpert distinguished nine regional variants of the Yamnaya culture (Rassamakin/Nikolova, 2008, 52 citing Мерперт, 1968, 14ff.): the 'Volga-Ural variant' located between the rivers Volga and Ural with its subvariants at the lower Volga, the middle Volga and in the Ural region, the 'Precaucasus variant', the 'Don variant' at the lower Don and the valley of the western Manych River, the 'Severskii Donets variant' located on the right bank of the Severskii Donets river between modern Kharkov and Lugansk, the 'Azov variant' on the steppe of the North Azov Sea coast, the 'Crimea variant', the 'Lower Dnieper variant' from the Orel and the Ingul rivers to the Black Sea coast, represented in six sub variants, the 'Northwest variant' at the border between the steppes and forest-steppes of the middle Dnieper and west of it, and finally the 'Southwest variant' between the Bug and the Danube (Fig. 2.3). O. G. Shaposhnikova further subdivided the Yamnaya culture in the North Pontic region into five local variants, namely the variants 'Severskii Donets', 'Middle Dnieper', 'Lower Dnieper', 'Azov-Crimea' and 'Southern Bug' (Rassamakin/Nikolova, 2008, 54 citing Шапошникова, 1985, 347ff.).

The number of regional variants and their characteristics are still under debate and there is no clear understanding of whether certain cultural groups are distinct cultures in their own right or Yamnaya variants (Rassamakin/Nikolova, 2008, 51). This is especially disputed for the Budzhak culture in the northwest Black Sea area, the Poltavka culture of the River Volga and the Kemi-Oba culture in the southernmost part of the North Pontic region (cf. Kaiser, 2012, 21–27).

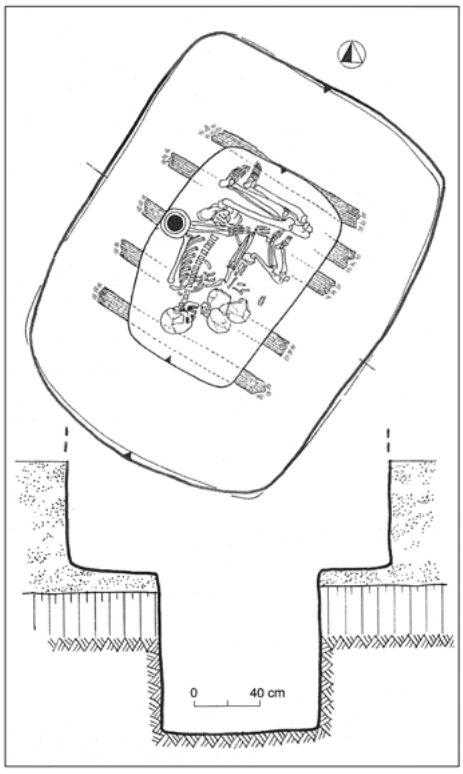


Fig. 2.4 | Yamnaya burial (Zavadskie Mogily, kurgan 7, burial 28) (after Bunjatjan et al., 2006, 212 fig. 70, 2).

2.1.3.3 Burial tradition

Although the characteristics of the burial tradition differ regionally, there are a number of common elements. Most characteristic for the Yamnaya culture are the kurgan burials, which were erected across the whole distribution area, preferably in prominent positions, singularly or in clusters. The burial mounds of the Yamnaya period consist of several earthen embankments covering one or, less frequently, several burials (Ślusarska, 2006, 43). Grass sods were used to build the mounds (Nikolova, 2006b, 13), which were flattened, segmented and sometimes encircled by oval or round ditches (Shishlina et al., 2009, 481). Burial pits were mainly rectangular or oval in shape (Fig. 2.4). The walls of the burial pits were commonly smoothed, sometimes with the addition of lateral terraces. The pits may be covered by wood, reed or re-used stone stelae (Anthony, 2007, 339) and there is sometimes evidence of post constructions. Orientations of the graves vary, with W–E and NW–SE orientations most common in the North Pontic. The skeletons were usually buried in supine positions with crouched legs or crouched on the side but some regional variations occur. Burial objects are generally scarce. Ochre occurs both in pieces and as colouring on skeleton parts or on the grave bottom and there are ceramics with different shapes and decorations, for example vessels with round and V-shaped bottoms (Nikolova, 2006b, 14–23; Kaiser, 2010a, 193). Bone tools such as hammer-headed pins, tools and weapons of flint and stone in addition to adornment and tools made of arsenic copper alloys may also be found (Ślusarska, 2006, 43). Exceptional burials may be recognised by the addition of disc wheels, wagon parts or even complete wagons, mainly in the context of the later Yamnaya period (Rassamakin 1999, 152; Kaiser 2003, 338). 'Burials of craftsmen', which first occurred in the

Final Eneolithic period, suggest (local) metal work production and become more numerous in the Bronze Age as a characteristic feature of the subsequent Catacomb culture (Parzinger, 1998, 469; Bátora, 2002, 181–183).

2.1.3.4 Economy

Although it is no longer accepted that the Yamnaya communities followed a fully nomadic lifestyle, as suggested by some researchers (for example Shilov, 1989 based on Шилов, 1964; Кузьмина, 1996), most scholars suggest that the Yamnaya societies were semi nomadic or at least highly mobile (e.g. Мерперт, 1974, 112; Синицын, 1959, 184–185 cited in Anthony, 1986, 298). According to Y. Ya. Rassamakin (1999, 154) 'even a semi nomadic form of economy can only be proposed with reservations', although he uses the distribution of kurgans to suggest that the steppes were used for herding on a seasonal basis and that habitation was concentrated in the river valleys. Rassamakin assumes that animals were habitually seasonally pastured in an economic system that originated in the Eneolithic and was intensified in the Early Bronze Age (Rassamakin 1999, 151–154). Yamnaya settlement sites, though rare, have been recorded, in some parts of the distribution area of the Yamnaya culture (Parzinger, 1998, 468; Anthony, 2004; Kohl, 2007, 144). Based on a sufficient number of settlement sites discovered in the Lower Volga region, Otchir-Gorieva (Очир-Горяева, 2002, 122, 126 as cited in Kohl, 2007, 160) argues for mixed herding and agricultural practices in this steppe region. Anthony holds the opinion that the eastern Yamnaya groups, located east of the river Don, were more mobile than the western groups based on the limited evidence settlements in the Yamnaya distribution area west of the Don (Anthony, 2007, 304, 324). According to Bunyatyan, the Yamnaya cultural community can be regarded as 'mobile-settled or mobile with a limited settled pattern' (Bunyatyan, 2003, 276), in which crop-cultivation such as the cultivation of wheat, barley, hemp and millet, evidenced by imprints on ceramics, co-existed with pastoralism, the principal element of the economy (Bunyatyan, 2003, 274–275).

As stated above, the Yamnaya culture was very multifaceted, however, giving rise to the possibility of regionally dependant and varying economic systems. Shilov, for example, proposed several regional economic models for the North Pontic region, where sedentary people were located in the steppe/forest-steppe boundary, cattle-breeders inhabited the great river basins and mobile sheep-breeders occupied the southernmost area. Furthermore, the area north of the Caucasus was inhabited by settled communities practicing animal husbandry, while mobile stock-breeders were located in the Volga-Ural region (Rassamakin, 1999, 131 ref. Шилов, 1975a, 7–15, 1975b; Anthony, 2007, 327). In the northwest Caspian steppes the Yamnaya economy is characterised by pastoralism, including seasonal movement cycles, associated with seasonal settlement structures in the river valleys (Shishlina, 2004, 101–102; Shishlina et al., 2008, 244).

Metal working was another economic aspect of the Yamnaya culture. According to E. N. Černych the 'Circumpontic Metallurgical Province', which started its formation in the 4th millennium BC but was only fully developed at the beginning 3rd millennium BC, included the North Pontic steppes and adjacent areas as well as parts of the Carpathian-Balkan region. Characteristic features include the distribution of similar metal objects and most notably the new innovation of processing arsenic copper alloys, associated with the exploitation of copper deposits in the Caucasus Mountains, which is also connected to the Yamnaya culture (Chernykh, 1992, 54–56, cf. also Černych, 1991; Černych et al., 1991; Chernykh, 2008; but see also L. A. Černych, 2003).

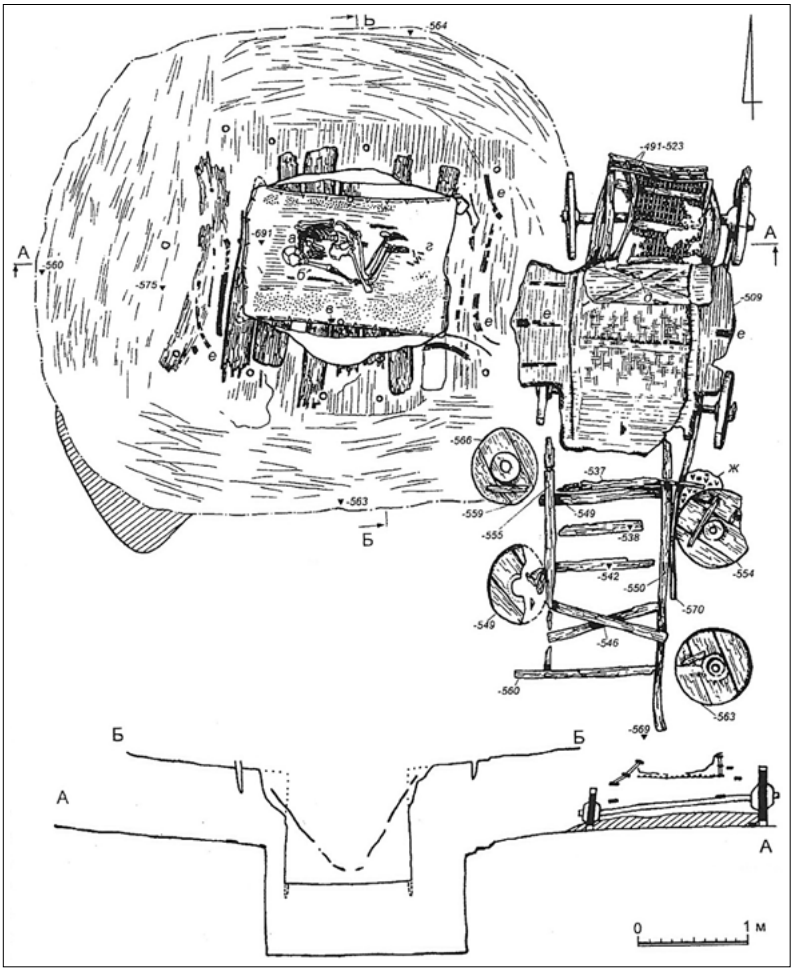


Fig. 2.5 | Novotitarovskaya wagon burial (Ostannii, kurgan 1, burial 150; after Gej, 2004, fig. 1).

In conclusion, the economic system of the Yamnaya communities forms the basis of an ongoing debate and will be discussed further in chapters 4 and 5.

2.1.3.5 Regional variants or distinct cultures of relevance

Two distinct cultures, or cultural variants, contemporaneous with the Yamnaya culture are relevant for this study and are briefly introduced below.

Burial complexes of the Novotitarovskaya culture are distributed in the Kuban region north of the Caucasus Mountains. The first excavated grave in this cultural context revealed a burial tradition that combined elements of the Yamnaya, the Catacomb and the North Caucasus cultures (Kaiser, 2012, 24 citing Козенкова, 1973). Two Russian scholars, V. A. Trifonov (Трифонов, 1991) and A. N. Gei (Гей, 2000), studied the Novotitarovskaya burial tradition in detail. Trifonov considers the key characteristics to be a tent-like construction above the grave and the deposition of disc wheels and whole wagons on platforms beside the skeletons, which are buried in a crouched position on their sides (Fig. 2.5) (Трифонов, 1991, 96 cited in Kaiser, 2012, 24). The burial mounds, covering the graves, are composed of different layers

Table 2.2 | A simplified chronology for the North Pontic steppe and its adjacent areas during the 3rd millennium BC (modified after Kaiser, 2011, table 1).

BC	NW Black Sea	Dniester to Dnieper	North Azov
2000	Developed Catacomb	Developed Catacomb	Developed Catacomb
2500/2450	Yamnaya	Yamnaya/Early Catacomb	Yamnaya/Early Catacomb
2800/2700	Yamnaya	Yamnaya	Yamnaya

and flattened at the tops. Burial objects are relatively infrequent and are consistent with the objects found in the Yamnaya and Early Catacomb culture graves in this region, with pottery vessels and hair rings found most frequently (Гей, 2000, 134; 159 cited in Kaiser, 2012, 25). The most remarkable burial objects of the Novotitarovskaya burials are wagons and parts of wagons, which have been recorded for a quarter of the graves. Gei suggested a reconstruction as heavy wagons with four disc wheels and a lattice-like superstructure, probably drawn by oxen (Gej, 2004, 177–184) and infers from these finds that they were also used as dwellings but mentions that other types of wagon might have been in common use outside the burial context (Gej, 2004, 185–186). According to Gei, the assemblage of burial pits, covered by wooden tent-like constructions, and platforms for the deposition of wagon (parts) sits stratigraphically between the Yamnaya and the second phase of the Novotitarovskaya and Early Catacomb culture graves (Kaiser, 2012, 25 citing Гей, 2000, 121).

Further to the east, the Poltavka culture, or variant, is distributed along the lower and middle Volga River, mainly on the east bank (Kaiser, 2005, 265). Scholars disagree as to whether this burial tradition should be labelled a distinct culture or a variant of the Yamnaya culture because of the lack of catacomb burial constructions in this region (cf. Anthony, 2004; Kaiser, 2012, 22 incl. Russian references). P. F. Kuznecov radiocarbon dated the Poltavka culture to the first half of the 3rd millennium BC, between 2900 and 2200 cal BC, superseding the Yamnaya culture, which dates to 3400 and 2900 cal BC in the Volga-Ural region (Kaiser, 2012, 23 citing Кузнецов, 2007; cf. also Anthony, 2007, table 13.3; Koryakova/Epimakhov, 2007, 47 fig. 2.1). N. K. Kačalova suggested a sequence of three chronological phases based on combinations of burial and pottery traditions (Kaiser, 2012 citing Качалова, 1967; 2001; 2002). As few settlement sites are known, and those are mostly interpreted as seasonal camps, the Poltavka culture is predominantly represented by burial finds (Anthony, 2007, 386). The burial ritual is characterised by a combination of distinct elements and those similar to the Yamnaya culture; Rectangular pit graves contain skeletons, which were laid in supine positions on their backs with extended or flexed legs or crouched on the side. The predominant skeleton orientation was east or northeast. Burial pits with niches are rare. Burial objects mainly include pottery, sometimes with herringbone pattern and ochre colouring, but also metal objects, organic mats and burnt animal bones. The graves, sometimes covered by wood or mats, were covered by small burial mounds that were in turn occasionally surrounded by circular ditches (Anthony, 2004; Anthony, 2007, 386; Popova, 2009, 304–305; Kaiser, 2012, 22–23). According to Popova, the burials usually contained adult male individuals of higher status (Popova, 2009, 305). Anthony suggested mobile pastoralism as the basis of the economy of the Yamnaya

and Poltavka communities in the middle Volga region (Anthony, 2007, 326–330, 440 fig. 16.12). He interpreted the absence of caries in many human remains of the Yamnaya and Poltavka culture as an indicator for a diet very low in starchy carbohydrates, which for him is a characteristic of non-settled and non-agricultural communities, a theory that he finds confirmed by short, intense uses of burial mounds (Anthony, 2007, 326–330). However, an intense use of burial mounds would seem rather to contradict circular mobility patterns.

2.1.4 The Middle Bronze Age[6] Catacomb culture period

2.1.4.1 Chronology

At the beginning of the 20th century V. A. Gorodtsov proposed a cultural-chronological scheme for the Early Bronze Age in the East European steppes with three succeeding periods. Based on observations of burial constructions and their positions in the burial mound, Gorodtsov placed the Catacomb culture, which is characterised by graves with catacomb constructions, between the Yamnaya and Srubnaya cultures. Today, however, radiocarbon dates have revealed that the Late Yamnaya and the Early Catacomb cultures coexisted for some time. The overlap of several hundred years with the preceding Yamnaya culture pushed the beginning of the Catacomb culture several hundred years earlier than originally suggested by Gorodtsov (Kaiser, 2003, 5–6; Rassamakin/Nikolova, 2008, 52).

The beginning of the Catacomb culture in the area between the river Don and the northern Caucasus Mountains can be absolutely dated to the early 3rd millennium BC, more precisely to 2800/2700 cal BC, and comes to an end around 2000 cal BC (Table 2.2) (Kaiser, 2003, 6; Ślusarska, 2006, 63). Similar dates are given for the North Pontic region, where the Early Catacomb culture is thought to have emerged about 2800/2700 to 2500 BC, coexisting with the Yamnaya culture and followed by the developed phase of the Catacomb culture that lasted until 2000/1900 BC (Pustovalov, 1994, 117; Kaiser, 2011, 195). A series of ^{14}C dates of the Early Catacomb culture at the river Molochnaya in southern Ukraine range between 2900 and 2600/2500 cal BC, while the beginning of the developed phase of the Catacomb culture at the Lower Dnieper dates to 2450/2400 cal BC (Govedarica et al., 2006, 108). Slightly later dates are given for the northwest Caspian region, for which corrected ^{14}C dates from Kalmykian kurgan cemeteries suggest the Catacomb culture to last from 2600 to 2000 cal BC. The Early Catacomb culture can be dated there to the time span between 2600 and 2350/2300 cal BC, while the East Manych Catacomb culture ranges from 2500 to 2000 cal BC (Shishlina et al., 2000, 798; van der Plicht et al., 2006, 113, 125; Shishlina, 2008, 213 fig. 139; Shishlina et al., 2009, 481).

In 1955, T. B. Popova attempted to characterise the Catacomb culture as a whole, and was able to differentiate six regional variants and three chronological phases of the Catacomb culture based on typology (Kaiser, 2003, 5 citing Попова, 1955; Kaiser, 2006, 39–42). Although this early chronological division is still relevant, it is difficult to distinguish between regional and chronological differences on the basis of an internal chronology. The Catacomb culture is rather uniform in its early phase, where its distribution area is restricted to a territory limited by the Dnieper to the west. In this case, it is not possible to discern regional variants, whereas in the more developed phase, a variety of regional variants can be

6 According to Russian terminology the Catacomb culture is considered part of the Middle Bronze Age.

distinguished. The third phase of the Catacomb culture is not as distinct as the early and the developed phases and represents a transition to the following KMK (multiroller) or Babino culture. While all three chronological phases can be distinguished in the eastern distribution area of the Catacomb culture, only two phases can be discerned for the western Catacomb culture groups (Kaiser, 2005, 269; Govedarica et al., 2006, 95; Kaiser, 2006, 39).

2.1.4.2 Distribution and regional subdivision

According to current research, the Catacomb culture is thought to have originated in the eastern Azov region with the cultural characteristics spreading from there into adjacent areas, mainly the North Pontic-Caspian steppes. From north to south the Catacomb culture is distributed from the margins of the forest-steppe to the natural border of the Black Sea coast (Kaiser, 2003, 2; Anthony, 2004). In the west the Catacomb culture is bounded by the river Prut and the mouth of the Danube and in the east by the lower and middle Volga and the Caspian Sea (Kaiser, 2012, 40). Single archaeological finds in modern Romania may indicate interaction between the local cultures of the northwest Pontic region and the people of the Catacomb culture (Kaiser, 2003, 7 citing Тощев, 1987), although the influence of the Catacomb culture on the areas west of the river Prut is generally low and the Catacomb culture is less integrated in Circum-Pontic interactions than the preceding Yamnaya culture (Kaiser, 2003, 339).

As mentioned above, the first and only researcher to work across the whole distribution area of the Catacomb culture was T. B. Popova (Попова, 1955) who was able to distinguish six regional variants (Kaiser, 2005, 269). Her subdivision was based on a much more limited amount of data than exists today, but, despite discrepancies in the regional distribution, her regional groups in the eastern part of the Catacomb culture distribution are still accepted (Kaiser, 2012, 28). L. S. Klein (Клейн, 1962) regarded the regional variants as representing distinct cultural groups that are only united by the common element of the catacomb burial. On this basis he introduced the term *cultural-historical community of the Catacomb cultures* or *Kulturhistorische Gemeinschaften der Katakombengrabkulturen* (Anthony, 2007, 307). Several of the regional variants of the Donets, Azov, Nikopol', Srednedon and Precaucasus regions, defined by Klein as distinct cultures, are still counted among the distribution area of the Catacomb culture as of today (Kaiser, 2003, 3 citing Клейн, 1970). Further studies by various scholars on the internal organisation of the Catacomb culture were constrained to distinct regions due to the huge increase in the number of known and excavated burial complexes (cf. Kaiser, 2012, 29–32 with an overview of the relevant literature). The most extensive of these regional studies was conducted by S. Zh. Pustovalov (Пустовалов, 1992; Pustovalov, 1994), who worked on the Catacomb culture between the lower Don, the Ingul and southern Bug. Pustovalov was able to distinguish between two separate cultural provinces: an eastern group in the area east of the Dnieper and a western group comprising cultural phenomena on the right bank of the Dnieper (Kaiser, 2005, 269; Ślusarska, 2006, 24). A more nuanced approach to the developed phase of the Catacomb culture allows the definition of the following regional variants, also referred to as groups or cultures (cf. Kaiser, 2012, 28 fig. 6): the variants or cultures Ingul, Dnieper-Azov, Donets, Bakhmut, Middle Don, the Poltavka culture, the Precaucasus (Manych) culture and the North Caucasus culture (Fig. 2.6).

There is no doubt in recent research about a continuous development from the Yamnaya to the Catacomb culture and a coexistence of Yamnaya and Early Catacomb culture for several hundred years (Kaiser, 2012, 33). The lower Don basin and the Azov Sea coast to the Dnieper, the distribution area of

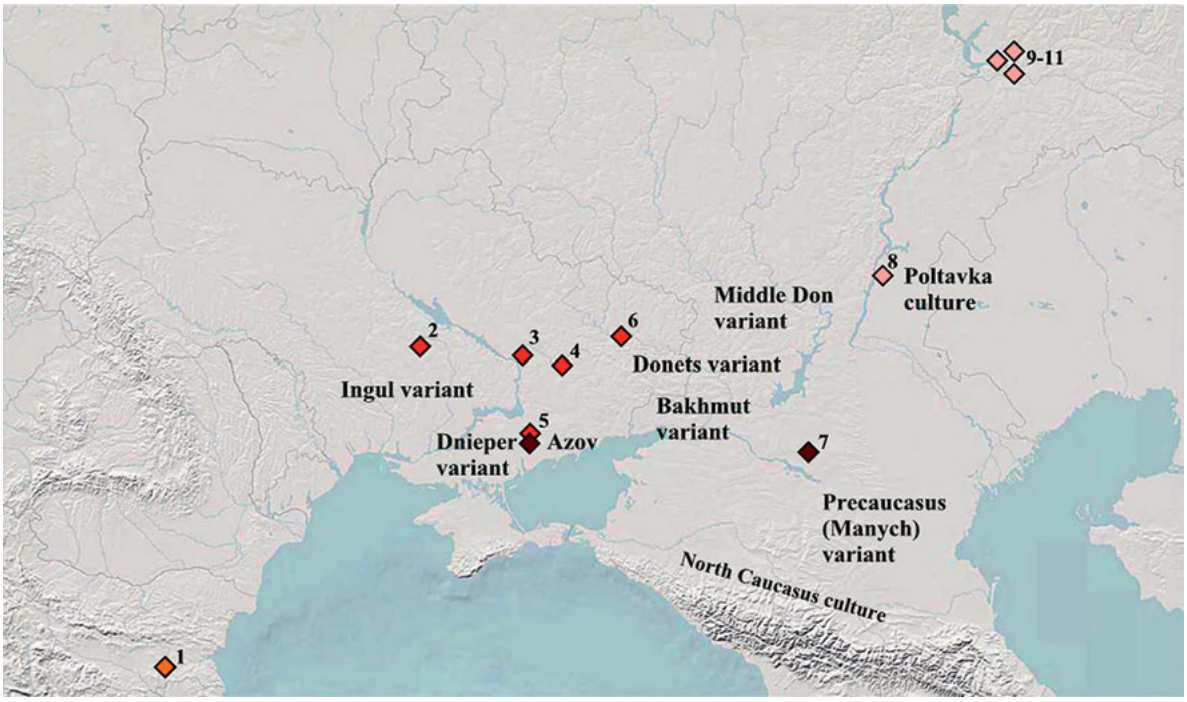


Fig. 2.6 | Cultural groups or variants of the Developed Catacomb culture horizon (modified after Kaiser, 2012, underlying map © D. Bordon). Samples [Middle Bronze Age (orange), Early Catacomb culture (dark red), Developed Catacomb culture (light red), Poltavka culture (pink)] were obtained from the following sites: 1 Boyanovo, 2 Kirovograd, 3 Peshtchanka, 4 Shakhta Stepnaya, 5 Vinogradnoe, 6 Nevskoe, 7 Sukhaya Termista II, 8 Politotdel'skoe, 9–11 Kalinovka I, Nikolaevka III, Podlesnyi.

the Donets culture or variant, are commonly regarded as the area of origin of the Catacomb culture (Братченко, 2001; Shishlina, 2008, 137; Otroschenko, 2010, 30). However, the origin of the Catacomb culture and the circumstances that led to its development are still debated. Kiyasho (Кияшко, 1999) proposes three phases for the transition from pit graves to graves with niches and T-shaped catacombs to catacombs in association with changes in the burial rite and burial objects. Other scholars believe the Catacomb culture originated from intensive interactions between the Yamnaya and contemporaneous cultural groups in the Caucasus. Bratchenko (Братченко, 2001), for example, regards the Catacomb culture as a product of interactions between the Precaucasus region and the steppe cultures. According to Rysin (Рысин, 2007), the culture developed from the dolmen culture in the northwest Caucasus (cf. Kaiser, 2012, 33–35 for Russian references; see also Otroschenko, 2010, 30).

2.1.4.3 Burial tradition

From 2800/2700 cal BC onwards, the tradition of the catacomb as a new grave construction emerged along the river Don and spread across the North Pontic steppes roughly to the Dnieper River. In this early phase, catacomb burials occurred alongside pit graves. In the Early Catacomb culture, the predominant crouched burial position and burial objects remained the same as in the Yamnaya culture (Fig. 2.7) (Kaiser, 2010b, 22). Burial objects were generally modest and uniform, although the number of burial objects increased in comparison to the preceding Yamnaya culture. The most common burial

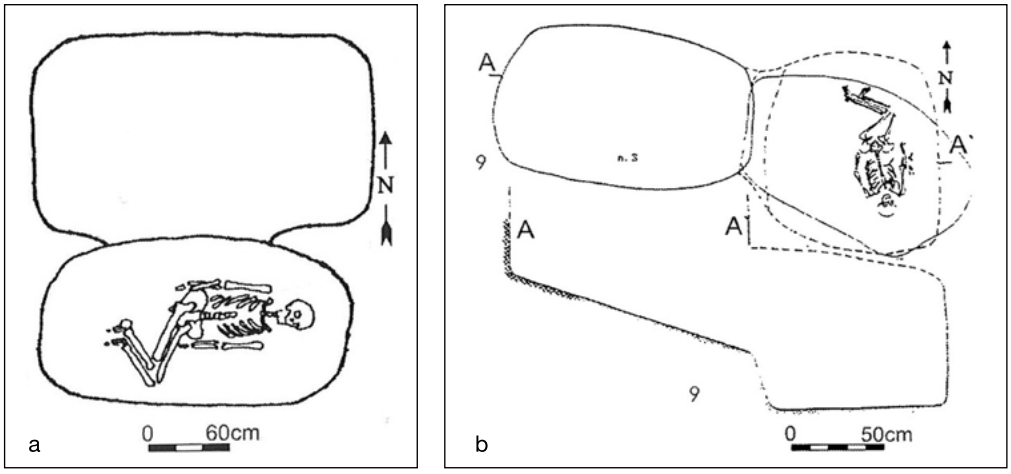


Fig. 2.7 | (a) Yamnaya-Catacomb grave of the Kuma-Manych Depression, Chograysky V, kurgan 8 grave 2 (after Shishlina, 2008, fig. 97), (b) Early Catacomb grave in the eastern Stavropol Hills, Chorgay VIII, kurgan 20 grave 3 (after Shishlina, 2008, fig. 78).

objects of the Early Catacomb culture were ceramic vessels with round bottoms bearing herringbone and combed decorations, and bone adornment such as hammer-headed pins. Sometimes extremely crouched burials are placed in spacious rectangular, sometimes T-shaped, burial chambers with the entrances sometimes blocked by stones (Kaiser, 2011, 204–205).

The Early Catacomb culture in the Caspian steppes has been extensively researched and its main features are summarised below as an example (cf. Shishlina, 2008, 132–134): Primary burial mounds and skeletons in extended supine positions predominate. Skeleton orientations vary, and special rites like post-mortem decapitations occasionally occur. The catacomb graves are of different shapes but mainly T-shaped. While the entrance of the catacomb is sometimes blocked by wood or stones, the grave chamber is furnished with mats and wood. Occasionally pillows and mats are found below the skeletons, and ochre colours skeletal bones and the chamber. Burial objects comprise ceramics including ritual incense burners and clothing ornaments, more infrequently weapons and tools and clay models of wagons and wheels. Hammer-headed bone and copper pins that are already characteristic of the late Yamnaya phase also occur in the graves of the Early Catacomb culture.

A developed phase of the Catacomb culture emerges around 2500 cal BC (Fig. 2.8). In this developed phase, distinct regional variants can be observed associated with an extended distribution of the Catacomb culture variants across the steppe and forest-steppe to the Caucasus and Black Sea and from the Danube to the middle Volga. There is little difference between the Yamnaya and the Early Catacomb culture archaeologically and anthropologically, the significant changes seeming to occur towards the developed phase of the Catacomb culture. Skeleton positions show a larger range of variation, although there is a general discussion about the emergence of crouched and supine skeleton positions being chronologically or spatially related with supine burials in the western Catacomb culture variants and crouched burials in the eastern groups (Kaiser, 2003, 39–43, 333–335). Burial objects also tend to be more varied.

The westernmost feature of the Developed Catacomb culture is the Ingul variant, distributed from the lower Dnieper region to the west. It is characterised by supine burials on the back in oval grave chambers with oval entrances. Usually, catacombs were dug into pre-existing burial mounds, often in

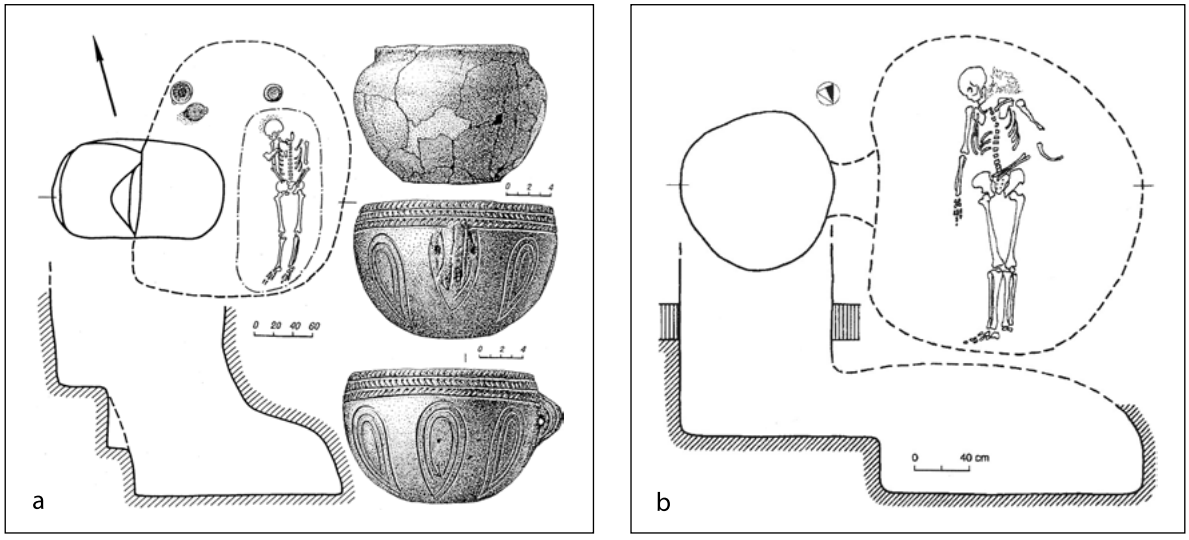


Fig. 2.8 | Burials of the Developed Catacomb culture: (a) kurgan in the vicinity of Ordzhonikidze (Bunyatyan, 2003, fig. 17.5), (b) Kruglaya Mogila, kurgan 7, grave 7 (Bunjatjan et al., 2006, 151 fig. 8.1).

the southern section of the mound. In contrast to the Yamnaya culture, the arrangement of the graves follows the *Hügelrandprinzip*, introduced by A. Häusler (Häusler, 1976, 26–27) to refer to the orientation of the graves with their long side facing the centre of the burial mound and the entrance on the other side. The entrances of the burial chambers are sometimes blocked by wooden wheels (Ślusarska, 2006, 46; Otroschenko, 2010, 32). Wood or stones occasionally cover the entrance shafts of the graves. Occasionally, bones are pushed together at a later date to make room for additional burials or to imitate a crouched position, an indicator of post-mortem rituals (Kaiser, 2003, 340). The burials are accompanied by burial objects like stone axes and maces, bronze and metal objects, a specific pottery style, wooden vessels and arrowheads of a distinctive type. Special features such as ochre foot prints and clay-modelled skulls occur. Commonly, burial chambers include organic foundations, pieces of ochre, chalk and charcoal or ochre staining, animal bones and ceramics. Tools and adornments of flint, stone, and arsenic copper alloys as well as bone adornments are present in small numbers.

Detailed descriptions of further variants of the Developed Catacomb culture are difficult to find in non-Russian literature. Therefore, a number of characteristics will be listed without an extensive characterisation of these Catacomb culture regional groups. The Donets variant, for example, and the eastern Catacomb culture groups are characterized by crouched burials laid on their sides. Ceramics such as pots, bowls, censers and pedestal bowls as well as bronze and stone objects are common grave goods (Otroschenko, 2010, 32). The Kharkov-Voronezh variant at the middle Don is also characterized by crouched burials on the side. These are placed in H-shaped catacombs or pits, which are commonly coloured by ochre or chalk, and mainly oriented towards the centre of the burial mound (Otroschenko, 2010, 33). In the Dnieper-Azov variant, however, T-shaped catacombs with rectangular to oval grave chambers and rectangular shafts are predominant. Skeletons are slightly flexed on the back or on the right side. Typical burial objects include round-bottomed vessels with little ornaments and bone objects such as hammer-headed pins (Ślusarska, 2006, 46 citing Санжаров, 2001). The tradition of cenotaph burials and the addition of grave goods imply a developed interaction system and are characteristics of the East Manych Catacomb culture, suggesting a relatively high level of mobility (cf. Shishlina, 2008, 248–254).

Some additional significant features of the Catacomb culture burial tradition should be mentioned here. One of these features is the inclusion within the graves of metal objects, which are at first made of copper and later on of sophisticated alloys of copper with arsenic. Since bronze weaponry, of which shaft-hole axes and daggers stand out, can probably be interpreted as status symbols or symbols of power, their presence not necessarily implying a martial context (Kaiser, 2003, 338), although Rassamakin, for example, regards the bronze weaponry connected with Catacomb culture burials as an indicator of increased warlike potential (Rassamakin, 1999, 154; cf. also Pustovalov, 1994, 99). According to Anthony, the emergence of bronze objects in burial contexts indicates interaction between the steppes and the Caucasus Mountains (Anthony, 2004). Although E. N. Chernykh (e.g. Chernykh, 2008, 45) holds the opinion that the copper in the Caucasus was the only exploited source at that time, L. A. Černych (2003, 54) points out that copper sources in the Donets region were also exploited. The so-called 'burials of craftsmen' are associated with these metal objects. The emergence of tools for metal working is already established for burials in the preceding periods, i.e. single graves with casting tools for shaft-hole axes in the context of the Middle Eneolithic Kvityana culture and in the Early Bronze Age Yamnaya culture. However, the number of graves containing tools for metal working, mostly as *pars pro toto*, dramatically rises in the Developed Catacomb culture before disappearing again in the Late Bronze Age (Parzinger, 1998, 474; Kaiser, 2005, 266–268, 285–286; Kaiser, 2011, 206). Clay-modelled skulls are another distinct feature of the Developed Catacomb culture, which can be regarded as indicators for post-mortem practices. This practice is supported by finds of piles of bones in the catacombs, suggesting that earlier skeletons were put aside when new burials were added (Kaiser, 2003, 340; Otroschenko, 2010, 32; Kaiser, 2011, 206). Complete wagons with two to four solid wheels or incomplete pieces of wagons were usually not deposited in the burial chamber itself but in the entrance shaft of the Catacomb culture wagon burials (Belinskii/Kalmykov, 2004, 212–213). Evidence of single-seater, four-wheeled wagons with sidewalls as well as chariots with solid wheels exist from burials dating to the Catacomb culture (Gej, 2004, 177 citing Чередниченко/Пустовалов 1989, 1991; Černych, 1991). While complete wagons and multiple wagon parts are only associated with crouched burials, wooden wheels occur in association with supine burials and are deposited in front of the entrance to the catacomb (Kaiser, 2003, 230–240). As in the preceding cultures wagons or parts of wagons are seen as indicators of exceptional burials (Pustovalov, 1994, 99–101; Belinskii/Kalmykov, 2004, 217; Anthony, 2004), although some researchers such as V. A. Trifonov, E. V. Izbicer and A. N. Gei do not support this idea (Belinskii/Kalmykov, 2004, 217). Gei (2004, 184) refers to clay models that can be interpreted as representing covered wagons.

2.1.4.4 Economy

Although there are significantly more settlements dating to the Catacomb culture than to the preceding Yamnaya culture (Anthony, 2004), the character of most sites is unknown. The existence of long-term settlements is debated, but most known sites are interpreted as seasonal camps (Pustovalov, 1994, 87). They are mainly concentrated in the river valleys. In the North Pontic region these are the river valleys of the lower Dnieper, the Ingul, and the southern Bug, along the Black Sea coast and along the middle and perhaps also the lower Don. Moreover, they are also distributed in the open steppes in the vicinity of water sources. It is worth noting, however, that archaeological research concerning the Catacomb culture has mainly concentrated on the kurgans, and settlement sites of the Catacomb culture were often

not sufficiently examined to allow a reconstruction of the subsistence economy (Pustovalov, 1994, 87, 103; Kaiser, 2011, 195–196). The settlement layers at these sites are very thin and as a result, the sites are often regarded as being seasonal in character, probably being arranged along the seasonal stock migration routes. This does not necessarily mean that the Catacomb culture communities predominantly led a nomadic way of life, as there may be other explanations for these characteristics (Kaiser, 2010b, 26; Kaiser, 2011, 195). According to Bunyatyan, evidence for permanent settlements increases during the developed phase of the Catacomb culture (Bunyatyan, 2003, 276). According to Pustovalov, there is archaeological evidence of a mixed economy of agriculture, stockbreeding of cattle, sheep and goats, fishing but also hunting and gathering in the upper layer of the settlement Mikhailovka at the Dnieper, which corresponds to a later period of the Yamnaya culture (Pustovalov, 1994, 108–113, 126). Bunyatyan maintains that tools for grain processing occur in larger numbers than in the preceding Yamnaya culture and grain, like wheat and millet, becomes a component in the burial ritual, which indicates a more important role for agriculture (Bunyatyan, 2003, 276). On the basis of this archaeological evidence a semi-nomadic economy was proposed, with one part of the community staying in permanent settlements and practicing agriculture and a group of pastoralists moving around with the stock for some part of the year (Pustovalov, 1994, 87 citing Адрианов, 1985; Parzinger, 1998, 471–473). This was also proposed by Anthony, who explains the bifurcated economy and settlement structure as a reaction to the overgrazing of pastures, which – according to Anthony – can be seen in the building of Catacomb culture kurgans on overused soils (Anthony, 2007, 322, 330, footnote 41). Similarly, Bunyatyan (2003, 273, 276–277) suggested that the steppe communities of the Catacomb culture developed a flexible economic system combining principal reliance on stock-breeding initially with well developed agricultural activities playing an increasingly important role over time and into the Developed Catacomb culture. A similar seasonal migration pattern to the preceding Yamnaya culture, though wider-ranging, was suggested for the Caspian steppes. According to Shishlina (2008, 244), sites were also located in the terraced valleys of steppe rivers and their meanders and stock-breeding groups moved in circular patterns from rivers to watersheds and back to rivers with migration routes that could extend over hundreds of kilometres (Shishlina, 2004, 102–104). That said, it should be noted that the complex Catacomb culture society, consisting of multiple regional groups, was probably associated with not just one but several different economic systems (Pustalov, 1994, 125).

2.1.5 (South)westward steppe impact

2.1.5.1 History of research

The relationship between the North Pontic steppes and regions to the west and southwest during the Eneolithic or Copper Age and the subsequent Early Bronze Age has aroused the interest of a large number of researchers. This study will concentrate on the Carpathian-Balkan region, where the sample sites for stable isotope analyses are located.

Similarities between graves of the Eneolithic and Early Bronze Age in the Carpathian-Balkan region and those in the East European steppes had already been recognised one hundred years ago as a result of excavations of burials dating to these periods, such as those conducted by L. Zoltai in the first decades of the 20th century on the burial mounds in Eastern Hungary and by M. Garašanin in the 1950s. It was he that connected the long Copper Age flint blades on the Balkans with those from the

North Pontic region (Kalicz, 1969, 15–16), and these finds led G. Childe to write about migrations of 'nomad invaders from the east' (Childe, 1929; 206) and also about 'relations between the Hungarian Plain and South Russia (...) one way or the other' (Childe, 1929, 207–208). One of or the most prominent and consistent researchers postulating invading migrations was M. Gimbutas (e.g. in 1956; 1994; 1997), who explained the changes in archaeological remains of the Copper and Bronze Age from the Carpathian-Balkan region with invasions from the steppe people to the east including the North Pontic 'kurgan culture' (cf. Harrison/Heyd, 2007, 196; Kohl, 2007, 133). In her papers, Gimbutas postulated three successive waves of martial horse-riding and nomadic steppe people, the last one equivalent to the Yamnaya people, intruding into the Carpathian-Balkan region and destroying the peaceful local agrarian societies. Chronological discrepancies and the fact that the burial objects do not show a warlike potential to the degree she assumed, among other things, make her model problematic (Kaiser, 2011, 193). According to Harrison and Heyd (2007, 196) her approach is 'oversimplified and monocausal' and more to be regarded as a 'pioneering work'. Nonetheless, Gimbutas' work was very influential on subsequent research. One of her followers, H. Todorova (1986), postulated a Northern Pontic 'invasion' into the Balkans that destroyed the KGK VI complex and led to a hiatus at the transition to the Early Bronze Age. Until recently researchers such as D.W. Anthony, for example, assumed the Yamnaya-related burial mounds west of the North Pontic region indicated an intrusive and numerous 'immigration of a non-indigenous population' (Anthony, 1986, 301). In his migration model Anthony used the example of the westward Yamnaya 'migration' (Anthony, 1986; 1990; 2007; cf. Chapter 4.2.3). However, Anthony's ideas need to be treated with caution due to chronological and other discrepancies (Kaiser, 2010a, 196).

Other researchers did not go as far. I. Ecsedy, who published a catalogue on the excavated Hungarian pit graves in 1979, favoured the idea of a gradual influx of small population groups originating in the steppes (Ecsedy, 1979, 55) that 'left its marks on the cultural development in southeast Europe, although it did not have such catastrophic consequences as assumed by certain researchers' (Manzura, 1994, 266). Others, like J. Lichardus and M. Lichardus-Itten, simply stated that there was a North Pontic influence on the West that started in the Eneolithic and resulted in significant cultural and social differences (Lichardus/Lichardus-Itten, 1995, 31–56). The idea of infiltrating population groups was vehemently rejected by A. Häusler (first in 1974; 1976). According to Häusler, the developments in the steppes during the Eneolithic and Early Bronze Age had an autochthonous character and coherences in the archaeological remains appeared due to single infiltrations (Häusler, 1998, 148).

Developments in the East European steppes are interpreted as the results of interactions with the neighbouring sedentary societies. Rassamakin (1999, 103) explained the emergence of exotic archaeological remains in the Eneolithic in the North Pontic with long-distance exchange or trade of materials and objects (cf. Kohl, 2007, 133; see also critiques in Dergachev, 2002; Telegin, 2002). R. Harrison and V. Heyd (2007) published one of the most recent hypotheses regarding the North Pontic impact on the West Pontic area. Although the authors clearly reject Gimbutas' model of 'kurgan culture' invasions, they presume steppe population groups migrated west- and south-westward bringing along a 'Yamnaya package' of innovations (cf. Chapter 4.2.3.3) and novelties in the material culture as well as changes in the technological, social and economic spheres (Harrison/Heyd, 2007, 196, 197 fig. 45). The idea of migration groups bringing a 'package' of changes, however, has been repeatedly criticised in the last few years (e.g. Kaiser, 2010a, 198; Hansen, 2011, 174; Ciugudean, 2011, 29–30).

An overall monographic summary of the graves with steppe characteristics west of their distribution area is missing and only single regional studies have been conducted, for example by N. Kalicz

(1969; 1998), Ecsedy (1979) and recently by T. Horvath (2011) for the graves in Hungary and by I. Panayotov (1989), Kitov et al. (1991), L. Nikolova (1999) and St. Alexandrov (2011) for those in Bulgaria (cf. Harrison/Heyd, 2007, 194 for further studies). A recent paper on Yamnaya burials west of the Black Sea was published by Heyd (2011).

2.1.5.2 Late Eneolithic period

Contacts between the North Pontic steppes and the regions to the west and southwest are evident as early as the Early Neolithic. The appearance of metal objects in the area of the Lower Volga, which belong to a Balkan context (cf. Pernicka et al., 1997), show one-way connections between these two regions (cf. Kohl, 2007, 133). Combined with other archaeological finds, for example mace heads and animal-headed stone sceptres, they can be seen in the context of an early *Carpathian-Balkan Metallurgical Province*, as defined by Chernykh (1992, 48–53, fig. 2.7), as early as the 6th millennium BC. Since the middle of the 5th millennium BC new ideas and imported objects are not only demonstrated in the North Pontic but also in the Carpathian-Balkan area (Heyd, in press). While the steppe interactions during the so-called (stone) sceptre horizon have been well researched (Todorova, 1991, 90–91; Parzinger, 1998, 463; Chernykh, 1992, 35–53; Chernykh, 2008, 38; Govedarica/Kaiser, 1996), the interactions during the late Eneolithic are less well understood, despite the fact that interactions started to intensify in the Eneolithic period and the first single burials occurred west of the steppes at this time (Heyd, in press). Lichardus and Lichardus-Itten (1995, 48) were able to distinguish between four northwest Pontic contact phases. In the first phase, equating to the Eneolithic period, only single foreign objects appeared with no obvious changes in the local material culture. The following phases, however, corresponding to the Early Bronze Age, are characterised by the appearance of local cultures' objects in foreign burial contexts, followed by the adoption of ideological and cultural aspects of the foreign culture by the local cultures and finally the assimilation of foreign models in the way that new cultures usually develop. Burial mounds were already being built before the Early Bronze Age Yamnaya period. T. Horváth (2011, 95–98) suggested a subdivision into four chronological periods for the Eneolithic and Copper Age burial mounds in Hungary. Her period I covers the first ochre graves, while period II includes the first primary burials covered by burial mounds that date to the late Copper Age, the middle of the 4th millennium BC. Burials of an early Yamnaya phase, dating to the late 4th and early 3rd millennium BC, correspond to Horváth's period III and those of a late Yamnaya phase are equivalent to period IV. Horváth's distinction is in accordance with B. Jovanović' suggestion for three periods of Carpathian-Balkan steppe influence including an early phase of warrior cemeteries, to a late phase of late Yamnaya influence (Jovanović, 1986). St. Alexandrov was able to subdivide the burial mounds in Northern Bulgaria and Romanian Dobrudja into two chronological phases (Alexandrov, 2011, 313–315). His first phase includes crouched burials on the side in tumulus burials of the Cernavoda I culture, whereas his second phase refers to burials of the Yamnaya culture. In summary, burial mounds had already emerged before the time of the Yamnaya culture and can be related to interactions with the steppe region.

2.1.5.3 Early Bronze Age Yamnaya horizon

The question whether the Yamnaya phenomenon at the western end of its distribution area was related to Yamnaya population movements replacing earlier peoples, or was caused by slow infiltrations of ideas, including the new North Pontic burial traditions that spread into the Carpathian-Balkan region, is unresolved (e.g. Kalicz, 1998, 172; Harrison/Heyd, 2007, 194; Iliev, 2009, 244). Nevertheless, links between the North and West Pontic regions increase from the Late Copper Age onwards and peak with the Early Bronze Age Yamnaya phenomenon. There is evidence of intensive interaction between the North and West Pontic in the first half of the 3rd millennium BC in both directions, such as the emergence of distinct ceramic types such as pedestal bowls and vessels with asymmetric handles in the North Pontic region (Rassamakin/Nikolova, 2008).

R. Harrison and V. Heyd described a Yamnaya population infiltrating Eastern Europe and bringing a 'package of innovations' in economic, technological and economic spheres and in the material culture (Harrison/Heyd, 2007, 196, 197 fig. 45). This 'Yamnaya package' comprised eleven components: round barrows, single burials flexed on their backs in rectangular pits and covered in ochre, marked social positions and gender, special status of metallurgists and the new emergence of hoarding (in the social sphere), re-establishment of metallurgy and new weaponry (in the technological sphere), the domesticated horse in a pastoral economy and wagons as social markers in graves (in the economic sphere), and objects like hair rings of gold, electrum, and silver and cord decoration on pottery (in the material culture). According to Heyd (2012), this interaction led to new cultural phenomena associated with a formerly unknown social organization and lifestyle as well as new structures in economy and settlement organization. Several features mentioned by Harrison and Heyd (2007) were criticised by a number of researchers. E. Kaiser, for example, assumes that only novelties like the deposition of heavy wagons with disc wheels, stockbreeding based on cattle and the change to arsenic-copper alloy can securely be associated with the Yamnaya culture (Kaiser, 2010a, 198–199) and that the North Pontic impact on the Carpathian-Balkan region resembled oscillating structures involving smaller and larger North Pontic groups. Moreover, S. Hansen (2011, 174) highlighted that some of the innovations that are parts of Harrison and Heyd's 'Yamnaya package' cannot primarily be associated with the Yamnaya culture due to their earlier date in the second half of the 4th millennium BC.

If migrations of Yamnaya people to the west are assumed, the question of possible regions of origins arises. Anthony (2007, 363–364) suggests the area between the rivers Southern Bug, Ingul and Dnieper east of the distribution area of the Usatovo culture. The question of why the North Pontic steppe groups migrated westward is also under debate. Since researchers mainly agree on a predominantly pastoral economy for the Yamnaya groups, a change to less favourable climatic conditions may be suggested as a possible push factor (cf. Chapter 4.2.3 for a detailed discussion on possible migration reasons). Reasons like overgrazing of pastures or extreme population growth seem rather improbable (Anthony, 2007, 300–306, 364–365). The same is true for the exploitation of copper as a pull factor (Kaiser, 2010a, 199). Whilst the frequency of metal objects in the Carpathian Basin shows a peak in the first quarter of the 4th millennium BC, the importance of metal including the development of new metal forms in the Caucasus region increases (Hansen, 2011; Heyd, 2012). According to Chernykh (1992, 35–36; 2008, 40–41), the Carpathian-Balkan Metallurgical Province (CBMP) developed in the Copper Age and took part in the formation of the 'steppe belt' stockbreeding cultures. The established cultural-economic systems of the Copper Age collapsed dramatically at the end of the 5th and early 4th millennium BC and led to the development of the Circumpontic Metallurgical Province (CMP). Objects

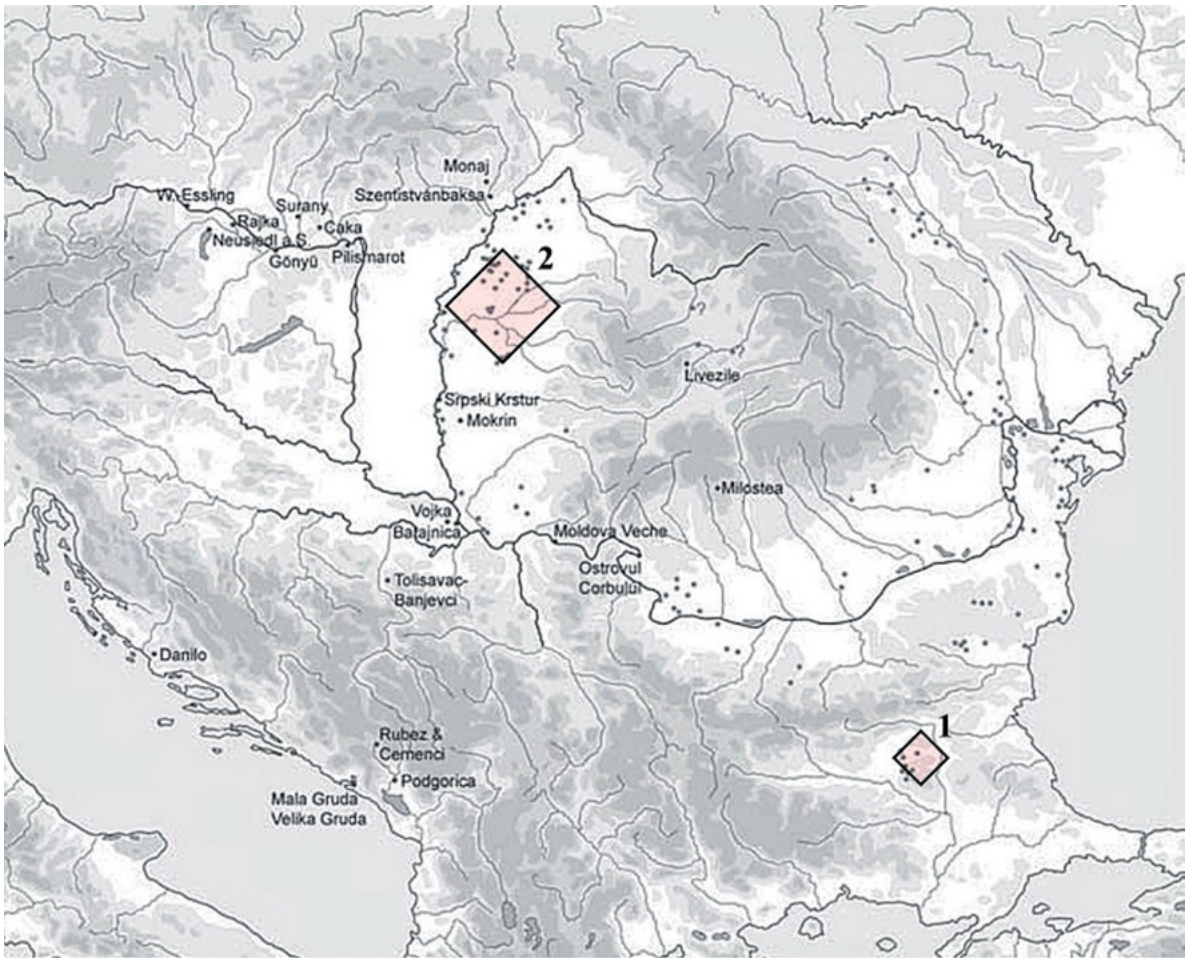


Fig. 2.9 | Distribution of graves with features that relate to the North Pontic region (after Heyd, 2011, 531 fig. 1). Early Bronze Age samples were taken from sample regions marked by diamonds: 1 in Bulgaria, 2 in Hungary.

like hair rings of gold, silver or copper, the tanged dagger, the awl with swollen middle shaft, and the reappearing single edged shafthole axe are regarded as indicators of intensified interactions with the North Pontic and the Caucasus regions (Kohl, 2007, 57–58; Heyd/Walker, in press).

A substantial number of burial mounds west of the core Yamnaya distribution area show characteristics that can be associated with the Yamnaya culture (Fig. 2.9). In general, the burial mounds associated with the Yamnaya are distributed in the steppe-like lowlands of the lower Danube, along the tributaries of the Danube and in the Carpathian Basin. Major concentrations of burial mounds are found in the central Carpathian Basin covering parts of Hungary, Serbia and Romania, the Dobrudja, at both sides around the lower Danube, in Romanian Moldova and on the Upper Thracian Plain in Bulgaria (L. Nikolova, 1999, 372; Heyd, 2011, 530–531).

The characteristics of the graves clearly correspond to the North Pontic tradition, although the phenomenon of burial mounds is not only typical for the Yamnaya culture but also for the contemporaneous local cultural groups in the Carpathian-Balkan region like, for example for the Ezero, Coţofeni and Baden cultures (L. Nikolova, 1999, 369). The characteristics of the Yamnaya burials in the Carpa-

thian-Balkan region can be briefly outlined as follows (cf. Kalicz, 1969, 28; Ecsedy, 1979, 35–36; Lichardus/Lichardus-Itten, 1995, 52; L. Nikolova, 1999, 369–389; Anthony, 2007, 362–366; Alexandrov, 2011, 315–317; Heyd, 2011, 533–535; Heyd, in press): The dead are predominantly placed in rectangular or, less commonly, oval, triangular or trapezoid burial pits. While burial objects are scarce, the grave pits are occasionally equipped with mats, textiles and leather fabrics that cover floors and walls. Additionally, step constructions occur, which hold wooden planks or stone slabs. Earthen burial mounds erected above the graves might contain features such as hearths or animal bones. In the northern Dobrudja and northeast Bulgaria stone stelae have been recovered. Besides the primary grave the kurgans frequently contain secondary burials, usually in connection with additional embankments. The burial mounds usually contain several secondary burials besides the primary grave. The kurgans are either clustered or isolated. The grave itself carries inhumations in supine position with drawn up knees or, less frequently, in a crouched position on one side, predominantly oriented West–East. Most of the skeletons are males. As already mentioned burial objects are extremely infrequent. There are adornments, most commonly hair rings of metal and necklaces and chains of perforated teeth or beads, only rarely metal implements, ceramics and flint objects. Ceramics and further objects are usually adopted from local cultural groups. Ochre spread and straining on the grave bottom or on skeletal remains as well as pieces of ochre are more frequent.

In Hungary, several Early Bronze Age tumuli containing crouched burials with prestige burial objects represent the local repertoire but in the graves east of the Tisza they show connections to other regions (Kulcsár, 2009, 355–356). In Bulgaria, Yamnaya remains are mainly present in the northeastern parts, but also in southeastern Bulgaria the archaeological evidence suggests that the Yamnaya culture and the local Ezero culture co-existed for quite a while. In Thrace the burial mounds show a mixture of Yamnaya and local elements, represented by local ceramics, for example. Iliev suggests that Yamnaya elements might have spread to Bulgaria mainly after 2900 BC (Iliev, 2009, 241–242). Alexandrov (2011, 315, 317–318) distinguishes between a first and second stage of 'Pit Grave Culture burials' for the regions in Bulgaria, where Early Bronze Age burial mounds occur. In the early phase, which can be dated to the Zimnicea-Celei-Ezero A1 horizon and the Cernavodă II culture, burials show typical Yamnaya characteristics and wide-ranging skeleton positions, whereas in a second phase, connected with the so-called 'Budjak' groups in the northwest Pontic region and parallel to the Glina III and Edineț cultures, semi-supine skeleton positions and secondary burials are predominant (Alexandrov, 2011, 315).

Since the newly arriving Yamnaya groups did not enter an unpopulated space, Heyd proposes three possible scenarios for the impact on the eastern European local settled and farming groups: Either Yamnaya people took over burial aspects of the local or neighbouring societies, the neighbouring societies adopted Yamnaya burial aspects, or people lost their original identities and merged into new ones. Interactions could have been peaceful, violent or neutral; according to Heyd it was probably a mixture of all three elements due to a large range of local cultural societies with varying cultural and economic backgrounds that dealt with the newly arriving Yamnaya people in different ways (Heyd, 2011, 538–539). Kulcsár (2009, 356) suggests a blending of migrating and local populations with a prominent role for the migrants, reflected in prestigious tumulus burials. D. Vollmann emphasizes the importance of the East Hungarian 'Pit Grave Culture' that is associated with North Pontic elements for the development of the 'Makó-Kosihy-Čaka' complex (Vollmann, 2009, 271).

A substantial number of the several hundred burial mounds that are known in the regions west of the North Pontic steppes have their origins in the 4th and 3rd millennia BC and some of these show

affiliations to the North Pontic steppes. Since the majority of the excavated kurgans are not published yet, it is difficult to interpret the graves culturally (Heyd, 2011, 529).

In Hungary, tumuli containing crouched burials with prestige burial objects and with possible connections to the Yamnaya culture are located east of the Tisza and along the western bank of the river (Ecsedy, 1979, 14). A couple of these mounds were situated along major routes, important river crossings or at sites of importance (Kulcsár, 2009, 356). There are two possible routes to reach the Carpathian Basin: one along the Danube via the Iron Gate and the second via Romanian Moldova and the east Carpathian Mountain passes (Heyd, 2011, 532). A relationship to the Livezile group, which is distributed in Western Transylvania, is suggested by the characteristic inhumations under burial mounds, although there are no pits and sometimes stone slab covers (Ciugudean, 1995, 147; 1998, 67–68; 2011, 29; Dani/Nepper, 2006, 41–44).

The Early Bronze Age burial mounds in Bulgaria can be regionally subdivided (see L. Nikolova, 1999, 374–379). According to L. Nikolova (1999, 392) there are regions with burial mounds mainly associated with the Yamnaya, regions with mixed burial mound traditions, regions with burial mounds predominantly not associated with the Yamnaya and regions without burial mounds. Distinct differences exist between northeast Bulgaria, north central Bulgaria (Goran-Slatina group), northwest Bulgaria (Knezha-Turnava group), and eastern Upper Thrace, where the presence of a mixture of local Ezero and foreign Yamnaya culture is expected.

2.1.5.4 Middle Bronze Age Catacomb culture horizon

The impact of the North Pontic on the Carpathian-Balkan region is relatively minor during the Catacomb culture period. The latest burials underneath mounds west of the steppes date to the latest Glina III and post-Vučedol phase, which can be paralleled to the developed stage of the Catacomb culture in the North Pontic region (Kaiser, 2003, 312). The small number of burial mounds that have been excavated in these regions and the altering of burial traditions, where the typical North Pontic characteristics are partly missing, complicate the identification of Catacomb culture burials (Kaiser, 2003, 315–316).

Graves showing the characteristics of the Catacomb culture are missing in the Carpathian Basin and in the western part of the Danube plain in Romania and Bulgaria, since the western borders of the Catacomb culture are the rivers Dniester and Prut and the distribution area of the Catacomb culture groups is more or less restricted to the area north of the Black Sea (Lichardus/Lichardus-Itten, 1995, 53; Chernykh, 2009, 130). Single burials with catacombs are evident in Romanian Moldova, in northeast Muntenia and the Dobrudja region (Parzinger, 1993, 328; Kaiser, 2003, 314; Heyd, in press). There is no secure evidence for Catacomb graves in the territory of modern Bulgaria (Kaiser, 2003, 314), although the semi-supine position of skeletons in graves connected to the second 'wave' of 'Pit Grave burials' in northeastern Bulgaria might be connected to the Catacomb culture (Alexandrov, 2011, 318). The Catacomb graves west of the steppes are characterised by burial objects such as ceramics, often shapes in a North Pontic tradition, and ochre pieces and staining but grave goods are generally scarce (Kaiser, 2003, 314). In the burials with characteristics of the Catacomb culture that were analysed in the eastern part of Romania, supine and slightly contracted skeleton positions are predominant (Burtănescu, 1996, 88 table 1) and graves, partially constructed as catacombs, mainly contain male individuals (Kaiser, 2003, 314).

2.1.6 The Iron Age Scythian period

2.1.6.1 Introduction

One further period under study for the Eurasian steppes is the 1st millennium BC, which is characterized by the Scythian culture and the cultural groups related to it. Their high level of mobility, evident both from archaeological record and ancient written sources, qualifies the cultural groups of the Scythian period as comparisons for the Eneolithic, the Early and the Middle Bronze Age steppe groups that are the focus of the present study. Iron Age comparison samples were taken from five sites in the North Pontic area and one site in the Altai Mountains; as a consequence only the characteristics of these regional groups will be described in detail.

Our knowledge about the Scythian period in the West Eurasian steppes is based on archaeological as well as written sources. Excavations took place relatively early and concentrated on the necropolises with impressive burial mounds that were surrounded by 'normal-sized' kurgans. Despite having been frequently robbed, they generated valuable objects of precious metals, which encouraged archaeologists to conduct further excavations. In addition to this, a considerable amount of information about the Scythians came from the historical writings of ancient Greek authors due to the close interactions between the Scythian steppe communities and the Greek colonies along the Black Sea coast. The key aspects of Scythian culture will be discussed in the following chapter.

In common usage, 'the Scythians' refers to a number of regional groups that populated the steppe belt during the 1st millennium BC and shared common characteristics. More accurately, the term refers to a chronological and cultural phenomenon that was widespread across the Eurasian steppes between the 8th to 3rd centuries BC (Menghin/Parzinger, 2007, 23), rather than distinct tribes or peoples. The elements that united these disparate groups were cultural traditions and features like the Scythian animal style ornaments, the construction of enormous burial mounds for a prominent 'elite' within a stratified social structure and a specific mobile and widely nomadic lifestyle and economic system (Parzinger/Nagler, 2007, 60; Parzinger, 2010, 58). Two key characteristics of the Scythian period are in consequence the development of nomad pastoralism associated with population mobility and the formation of military units to protect animal herds and conquer new territory (Petrenko, 1995, 5). Furthermore, horse breeding and riding ability increased the adaptability to the environment, e.g. connected to the periodic change of pastures (Dvornichenko, 1995, 101; Koryakova/Hanks, 2006, 275). Those circumstances can increase the variability of mobility, economy and settlement ecology (Frachetti, 2009, 41). In contrast to this highly mobile lifestyle, the large hillfort settlements of the North Pontic region provide evidence of a sedentary component of this wider society, with the presence of crafts, trade and possibly agricultural activities (Parzinger, 2010, 58).

While the 'real' Scythians were based in the North Pontic region and its adjacent areas (Parzinger, 2004, 68), cultural groups further to the East shared similar characteristics and traditions, like the Sauromatians in the southern Ural steppes, the Sakians in the territory of modern Kazakhstan and the people of the Pazyryk culture in the Altai Mountains. These contemporaneous groups closely resembled each other in certain features, while maintaining different cultural identities (Menghin/Parzinger, 2007, 23).

2.1.6.2 Chronology and distribution of the Scythian cultural groups

The features associated with the Scythian culture first appear in the southern part of Siberia, the Tuva region, delineated by the northern border of Outer Mongolia to the south and by the western Sayan Mountains to the north. In the late 9th and early 8th centuries BC, there was in this area and indeed across central Asia, a move away from the cultural and economic continuity of the Bronze Age. New characteristics such as the development of the animal style, the phenomenon of horse-riding nomads, the erection of monumental burial mounds and the transformation of social structure and material culture emerged as common features (Parzinger, 2004, 29; Parzinger, 2010, 58). The horse-riding nomadism, in particular, was an entirely new form of lifestyle and economy (Parzinger/Nagler, 2007, 60; Parzinger, 2007, 35; Parzinger, 2009, 19). The following centuries saw changes in the material culture as well as economic and social changes evidenced in Scythian groups in the regions west of the Tuva region, i.e. in the territory of modern Kazakhstan, in the southern Ural region and in the southern part of modern Russia. In the first half of the 7th century BC these changes are also evident in the North Pontic region, regarded as the core zone of the Scythians. Evidence of the Scythian culture is even found in the lower Danube and in the Carpathian Basin, dated to some centuries later (Menghin/Parzinger, 2007, 24; Parzinger, 2007, 30). In the course of their western expansion, the Scythians can be seen to have had a strong influence on both the Thracians and, even further west, the Hallstatt culture. The westernmost evidence of contact is evident in finds of single objects in the territory of the late Lausitz culture (Parzinger, 2007, 47). The decline of the Scythian culture started in the 3rd century BC, when intense movements of new cultural groups and tribes in Central Asia started to displace the Scythians and cultural groups associated with them in most parts of their earlier distribution area. In the early 2nd century BC only a small Scythian population remained in the Crimea (Parzinger, 2007, 30; Parzinger, 2009, 26).

Although the lack of ^{14}C dates for most parts of the steppe belt is a major difficulty, there is a consistency between the most recent archaeological theory and the ^{14}C chronology that so far exists (Alekseev et al., 2001, 1105). Alekseev and colleagues compared ^{14}C data for kurgans and were able to determine three phases based on both archaeological and scientific results: a first phase covering the 8th and 7th century cal BC, a second phase from the 7th to the 6th century cal BC and a third phase between the 5th and 3rd century cal BC (Alekseev et al., 2001, 1106). The authors found the earliest Scythian monuments in the Tuva region and in the Tagar culture of Southern Siberia to be contemporary but that the first period of the European kurgans was of a later period. In the second phase the oldest dates from southern Siberia and Central Asia overlap indicating that they are roughly contemporaneous. The same is true for the Sayan-Altai and the kurgans in the European steppes. The Pazyryk kurgans in the Altai and the Seven Brothers kurgans in the Kuban region are consistent in ^{14}C dates and archaeology. Further radiocarbon dates obtained for the Scythian European burial mounds support the suggested internal Scythian chronology (van der Plicht, 2004).

In a general sense, the appearance of Scythian cultural artefacts is more or less restricted to the Eurasian forest-steppe and steppe belt and to the steppe-like plains in Eastern Europe between the Yenisei River in the East and the middle Danube in the West (Fig. 2.10) (Parzinger, 2007, 43; Parzinger, 2010, 58). With this region, the North Pontic steppe belt is regarded as the core zone of the Scythian culture. A concentration of Scythian 'elite' burial mounds in the lower Dnieper region relates to the area, recorded by Herodotus, where the Scythian kings were buried (Parzinger, 2007, 47). Another concentration of

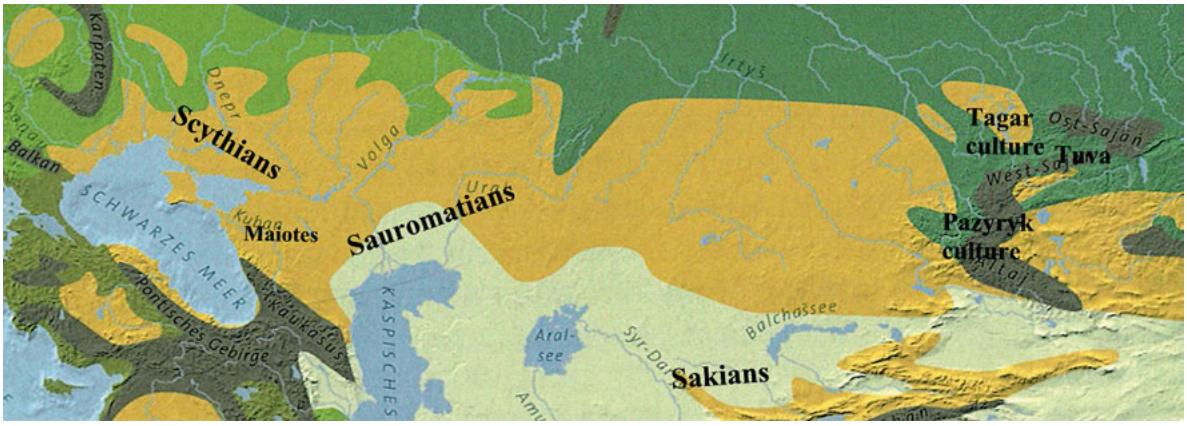


Fig. 2.10 | Distribution of the major cultural groups of the Scythian period (modified after Menghin/Parzinger, 2007, fig. pages 1, 28).

Scythian artefacts occurs to the east of the Scythian 'homeland', in the Kuban region north of the Caucasus Mountains. There is evidence of the Sauromatians, and later the Sarmatians north of the Caspian Sea between the river Don and the southern Ural Mountains between the 7th and 4th century BC (Moshkova, 1995, 85). The Sakians are located in the territory of modern Kazakhstan. Towards the eastern border of the Scythian-related cultural groups the Tagar culture can be located in the Minusinsk Basin during the 7th to 3rd century BC, while the Pazyryk culture is situated in the Altai Mountains between the 5th and 3rd century BC. The earliest appearance of the Scythian culture can be confidently established in the Tuva region as early as the late 9th century cal BC, based on dendrochronological and ^{14}C dates from kurgan Arzhan I (Bokovenko, 2004, 24; van der Plicht, 2004, table 1 incl.^{14}C dates for Arzhan II, for example).

2.1.6.3 Historical sources for the Scythians

A wealth of myths and truths about the Scythian cultural groups are available to us now, written by antique authors. In the second half of the 8th century BC Homer was the first to write about the Cimmerians, equestrian nomads who lived in the distribution area of the Scythians. Hesiod, however, was the first to explicitly mention the Scythians in the 8th or 7th century BC (Parzinger, 2004, 10). The foundation of Greek colonies at the northern Black Sea coast in the 7th century BC intensified contacts between Scythians and Greeks and inspired several Greek authors to leave written evidence about their neighbours. In addition several Assyrian texts describe the Scythians and their traditions from another perspective (Parzinger, 2004, 25; Parzinger, 2007, 32).

Herodotus left the most relevant account of the Scythians, mainly his book Histories IV, written after his stay in Olbia during the 5th century BC. Although the credibility of Herodotus' texts is sometimes doubted in historical research, his account correlates well on the whole with the archaeological remains (Ivantchik, 2007, 238). In particular, Herodotus reported important facts about the burial traditions of Scythian kings, which were subsequently proven to be true by archaeological research. Herodotus was the first to explain that the dimensions of the kurgans were related to the social ranks of the dead, that humans and horses were sacrificed for the burial, and that spears were placed on both sides of the skeletons and exclusive burial objects accompanied the dead. On the other hand, some

details in Herodotus do not entirely equate to the archaeological remains, such as the exact location of the 'elite' burials of the Scythian kings (Ivantchik, 2007, 238). The written sources particularly describe the Scythian traditions in the North Pontic region, generally from a Greek perspective. Considerably less written evidence exists about the Scythian cultural groups further to the east. Intense contacts between groups in the western and eastern steppes are referred to by Herodotus (IV 24), who describes the travels of the North Pontic Scythians to the east, and Aristias of Prokonnesos who wrote of the immigration of the Scythians from Central Asia into the North Pontic region (Parzinger, 2004, 25).

The Greek authors mention a number of eastern Scythian tribes, such as the Argippeans, Issedones, Massagetaeans, and Sakians, but for the most part their cultural traditions are described in much less detail (Parzinger, 2007, 36–37). Some of the cultural groups of the Scythian period in the eastern part of the steppes are described in more detail. According to Herodotus, the Argippeans, for example, were a Mongoloid tribe in the eastern and northeast territory of modern Kazakhstan speaking a distinct language but wearing similar costumes as the other steppe tribes of the North Pontic Scythians. Their economy was based on animal husbandry and food gathering and they were in consequence highly mobile and lived in yurts. Their neighbours in Central Asia were the Issedones and Massagetaeans. Whilst the Issedones were described as peaceful stockbreeders, the Massagetaeans were said to have been warlike nomads of Central Asia with a society based on animal husbandry. To the south of these Central Asian tribes, in the Land of Seven Rivers, were the Sakians, a cultural group with strong similarities to the Scythians, for instance in their animal style ornaments, but with distinct features in their costume. The Arimaspians were thought to be an equestrian nomadic tribe of the steppes of western Siberia and northeast Kazakhstan, but Herodotus says almost nothing about the Siberian tribes north of the Sakians (Parzinger, 2004, 25–28 ref. Herodotus IV 26, 27, I 102).

2.1.6.4 Characterisation of the Scythian culture in respect to this study

Following the evidence from historical sources and archaeological findings, the cultural groups of the Scythian period are presumed to have followed a semi-nomadic or even nomadic mode of life. Initially, herding nomadism is associated with a high degree of mobility due to periodic, i.e. seasonal, movements according to the availability of grazing and this is characteristic for a large proportion of the Scythian cultural groups (Parzinger, 2009, 17; Wentz/de Grummond, 2009, 107; Scoryi, 2010, 70; Parzinger, 2010, 58). Another constant factor of life was warfare, and the ongoing competition for both pasture land and contacts between the east and the west of the steppe zone produced stratified social structures (Parzinger, 2007, 33–36).

The settlement history of the Scythian period has not been thoroughly investigated (Parzinger, 2010, 60), and temporary sites are difficult to detect archaeologically. Some researchers regard Scythian nomadism as an adaptation to changing climatic conditions in the 1st millennium BC (Povalahev, 2008, 16 citing Руденко, 1961, 2–15; Vinogradov, 1996, 77–88). While on one hand soil analysis points to a dryer climate (Demkin et al., 2000, 88; Povalahev, 2008, 21), pollen and animal bone analyses at sites in the Crimea and the lower Bug region indicate a cold and humid climate. Vinogradov (1996) follows Abrosov (1962) in seeing an inverse relationship between steppe and forest-steppe climate (Povalahev, 2008, 21). Herodotus (IV 46) reported that wagons not only served as a means of transport (like four-wheeled oxcarts) but also as homes (Parzinger, 2004, 78–79; Parzinger, 2009, 17). Sadly, archaeological

remains of portable homes such as tents or yurts and covered wagons are hard to find (Parzinger, 2007, 33). Although archaeological evidence for Scythian settlements is scarce and not yet well investigated, it is known that not all Scythian cultural groups were nomadic herders (Parzinger, 2010, 60). Huge fortified settlements, so-called *Gorodišče*, are known from the forest-steppe. These have some kind of *Akropolis* construction and emerge at the transition from the 5th to the 4th century BC (Povalahev, 2008, 43). These settlements point to settled communities with an elaborate system of crafts and trade and are suggested as providing home-bases for the Scythian 'elite' (Rolle et al., 1996, 84). Necropoleis and associated ritual places were found in the context of these settlements, and finds of burnt grains, burnt animal bones and wool indicate the presence of agricultural activities and the keeping of domestic animals (Rolle, 1972, 49–50). Another type of simple small settlements with round and quadrangular pit houses is in evidence at the transition from the 7th to the 6th century BC. Scythian settlements come to an end with the emergence of the Sarmatians at the transition of the 3rd to the 2nd century BC (Parzinger, 2004, 79–82). Both the nomadic and the settled Scythian groups conducted animal husbandry, mainly cattle and horse, but also sheep or goat. Sheep and horse play a major role on nomadic Scythian camp sites, but cattle outnumber horse and sheep on settlement sites considered semi-nomadic (Kohl, 2007, 158 citing (Гаврилюк, 1999, 154). Agriculture, particularly the cultivation of millet, barley and emmer wheat is evidenced for the Scythian groups in the Pontic forest-steppe (cf. Parzinger, 2004, 83–85; Povalahev, 2008, 60). According to Wentz and de Grummond (2009, 114) the Scythian diet included hunted game, gathered food and fish in addition to husbandry and agricultural products.

Environmental conditions of the Altai Mountains would suggest that stock breeding, especially cattle, to be the most favourable method of subsistence of the Iron Age Pazyryk culture. Archaeozoological evidence in the Talgar region points to a well-established pastoral economy during the Iron Age (Benecke, 2003, 78). A pastoral economy can probably also be assumed for the people of the Scythian period Pazyryk culture, who might be expected to follow patterns of vertical pasturing with summer mountain pastures and winter stays in the valleys (Bendrey et al., in press). Ethnographic studies of the Buryats in the 19th and 20th centuries show that there are several types of nomadic animal husbandry: Nomadism connected to cattle breeding involved two movements per year and the migration range was influenced by pasture size, the number of livestock belonging to each household and climatic and terrain features. In sub-arid zones, people moved several times a year, i.e. they stayed in winter camps for five months and in summer camps for three months. In between they moved to spring and autumn pastures for two months each. In the arid zone, the Buryats followed a semi-nomadism with permanent dwellings from September to May and summer pastures between June and August (Mansheev, 2009, 104–105). Vertical migratory distances were much more limited than migratory distances in the steppes, where horizontal movements took place (Bokovenko, 1995a, 255–256). There is evidence for mobile pastoralists in the Mongolian Altai that cover annual migrations in excess of 200 km (Bendrey et al., in press).

Numerous 'elite' burials, a novelty in the Eurasian Iron Age, are widely distributed on the steppes and can be regarded as indications of the development of a distinct social hierarchy during this period, often seen as the result of an economy based on nomadic husbandry and permanent conflicts with neighbouring groups (Parzinger, 2007, 34). According to Herodotus, the Scythian society consisted of a leading group where kinship played an important role. Polygamous leaders married several local and 'imported' women. In addition to the 'elite', the communities contained 'free' Scythians and slaves (Parzinger, 2004, 88–95). Although details varied, the basic principles of these burial mounds remain the same throughout the Eurasian steppes. The monumental kurgans are characterized by central burials with extremely rich burial inventories including prestige and import objects, a large number of

additional burials of human and faunal sacrifices, mainly horses, and an enormous number of gold objects (Parzinger, 2007, 34; Polin, 2007, 256; Parzinger, 2009, 17). Aside from the lower Dnieper area, exceptional burial mounds of the Scythian period are also concentrated in areas to the east, e.g. on the Crimean Peninsula, in the Kuban region, at the lower Volga and in the forest-steppe zone (Parzinger, 2007, 35, 43; Parzinger, 2009, 19; Wentz/de Grummond, 2009, 107).

One of the crucial points concerning $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses is conveyed in the texts of Herodotus (Polin, 2007, 256 ref. Herodotus IV 71–73), when he describes the burial ritual for the Scythian leaders. According to Herodotus, there were forty days of procession before the leader and a large number of followers and animals were buried in monumental burial mounds. This indicates that the dead probably died far away from the burial site. It follows that the establishment of a range of 'local' strontium and oxygen signatures (cf. Chapter 4.6.3.2) is rather pointless since, in this case, the burial location does not represent the last place of residence. It should be borne in mind, however, that these descriptions by Herodotus focus on the 'elite' burials in a specific period of time and a particular region [Polin (2007, 258) names several possibilities such as the lower Dnieper but also the north Caucasus], and are certainly not transferable to all Scythian burials.

2.1.6.5 Cultural groups touched upon in this study

The North Pontic region bordered by the lower Danube in the west and the Don or the Kuban region in the east is assumed to be the Scythian core zone even if the origins of the characteristics of the Scythian cultural groups developed far to the east. In the North Pontic area the Scythian cultural groups replaced the Cimmerians and are in evidence from the first half of the 7th century BC onwards. At the beginning of the Scythian period in the North Pontic region, graves were scarce with no discernible geographical pattern, added as secondary burials to already existing burial mounds or bedded under new mounds. Burials dating to the 6th and 5th centuries BC are more plentiful in the forest-steppe zone, while still infrequent in the steppes to the south (Rolle, 1972, 58). In contrast to the later phase the graves of the late 6th and early 5th millennia BC are concentrated in the Lower Dnieper region and the Crimean steppe, arranged in small groups rather than scattered across the steppe (Melyukova, 1995, 37; Povalahev, 2008, 38–39). In the course of the 5th century BC the number of new Scythian kurgans increases markedly and reaches a peak in the 4th century BC with numerous kurgan groups consisting of single large burial mounds surrounded by a number of smaller kurgans. There are cemeteries containing from fewer than ten and up to 100 kurgans with heights from 1.5 m to more than 20 m (Parzinger, 2004, 68–69; Polin, 2007, 258; Wentz/de Grummond, 2009, 107). At the end of the 4th century BC, the tradition of 'elite' burials seems to disappear in the region north of the Black Sea (Polin, 2007, 260).

In general, kurgans of small and large dimensions show similar types of construction and grave furnishing (Parzinger, 2004, 112). The North Pontic monumental burials of the Scythian period can be described as follows (see Polin, 2007, 258–260): Simple pit graves with wood and wattle cover are typical for the earlier Scythian period, whereas catacomb graves containing *dromoi* and one or more catacombs are predominant in the later period, especially in the 4th and 3rd centuries BC (Rolle, 1978, 158; Melyukova, 1995, 37; Ivantchik, 2007, 238). Between the 7th and 5th century BC the dead were simply buried on mats of various organic materials with the heads sometimes placed on wood or grass pillows, whereas from the 4th century onwards, the graves of the Scythian 'elite' also contained coffins and wooden sarcophagi (Ivantchik, 2007, 23). There is a predominance of supine positions of the skeletons

with head orientations to the west or northwest during the 6th to the 3rd centuries BC and of double burials in the 4th and 3rd centuries (Melyukova, 1995, 37–50). Herodotus reports the removal of the guts and the following embalming of the dead as rites belonging to the 'elite'. Due to bad preservation this could not be verified in the North Pontic, but these features are present in the Pazyryk culture of the Altai Mountains (Ivantchik, 2007, 240). Burial objects of the non-'elite' include weaponry such as arrows and spears, more rarely daggers and swords or shields. Adornment can include bracelets made of bronze or iron and unpaired bronze earrings. Rich graves also included finger rings, torques, vessels made of silver and gold and wooden vessels with golden ornamented plaques. Animal bones are interpreted as the remains of feasts. Greek ceramics occur occasionally in the environs of Greek colonies (Melyukova, 1995, 43). Burials of humans and animals such as horses were supplemental to the 'elite' central burials. Since they are of contemporaneous date, they are commonly interpreted as sacrifices (Ivantchik, 2007, 239). In the earlier period horses were buried in the grave chambers of the central burial, while in the 4th century they were placed in separate grave chambers. The number of accompanying horses varies between one and eleven, most frequently there are between one and three horses. Usually the horses were buried in highly ornamented harnesses (Melyukova, 1995, 44). While the entrances of the graves were closed by stones or wood, the graves were covered by mounds of sods and/or clay from the near surroundings. Commonly, several stages of mound construction can be distinguished. Black soil was also used to erect smaller kurgans. Stone circles were erected around some of the kurgans. Especially in regions with stone outcrops, e.g. the Dnieper Rapids and the lower Dniester, rings of stones or stone slabs were found at the base of the embankments (Rolle, 1978, 58; Melyukova, 1995, 36). The space between stone slabs and the sod or clay mound was filled with small stones. Ditches and occasionally ramparts, sometimes with one or two breaks in, were dug around the burial mounds.

B. N. Mozolevskii subdivided the North Pontic Scythian burial mounds of the 5th century BC into groups according to their original heights and assigned them to different social classes (Polin, 2007, 260). The lowest burial mounds were assigned to common Scythians of some kind of importance, while kurgans with an estimated original height of more than 7 m belonged to the Scythian 'elite'. In the steppe territory about 50 burial mounds that measure between 5 and 10 m in height are known today (Polin/Daragan, 2011, 189). The 'elite' burial mounds can show dimensions of up to 100 m in diameter and 8 to 10 m in height, the Alexandropol' kurgan (Fig. 2.11) even has a height of 21 m (Alekseev, 2007, 245; Polin/Daragan, 2011, 189). To date most of the excavated simpler burial mounds of smaller dimensions are unpublished and many of the 'elite' burials were robbed before excavations took place, which certainly brings such a subdivision into question.

Far less written information exists about the groups east of the core Scythian area, who were connected to a greater or lesser extent to the Scythian culture (Rolle, 1972, 70). There is, however, evidence of a range of cultural groups that were partly nomadic, and partly settled (Parzinger, 2004, 74). The further east one goes, the higher percentages of the Scythian cultural groups are genetically Asian, while in the North Pontic and its adjacent areas most of the individuals of the groups associated with the Scythian culture are genetically European (Parzinger, 2004, 77; Barkova, 2007, 118).

One study site of the eastern Iron Age cultural groups was considered in this study, which was the necropolis of Berel' in the Altai Mountains and associated with the Pazyryk culture. Most of the Iron Age burial mounds in the Altai Mountains are associated with the Pazyryk culture and belong to the later phase of the Scythian period, mainly to the 5th to 3rd centuries BC (Molodin/Parzinger/Ceveenzorž,

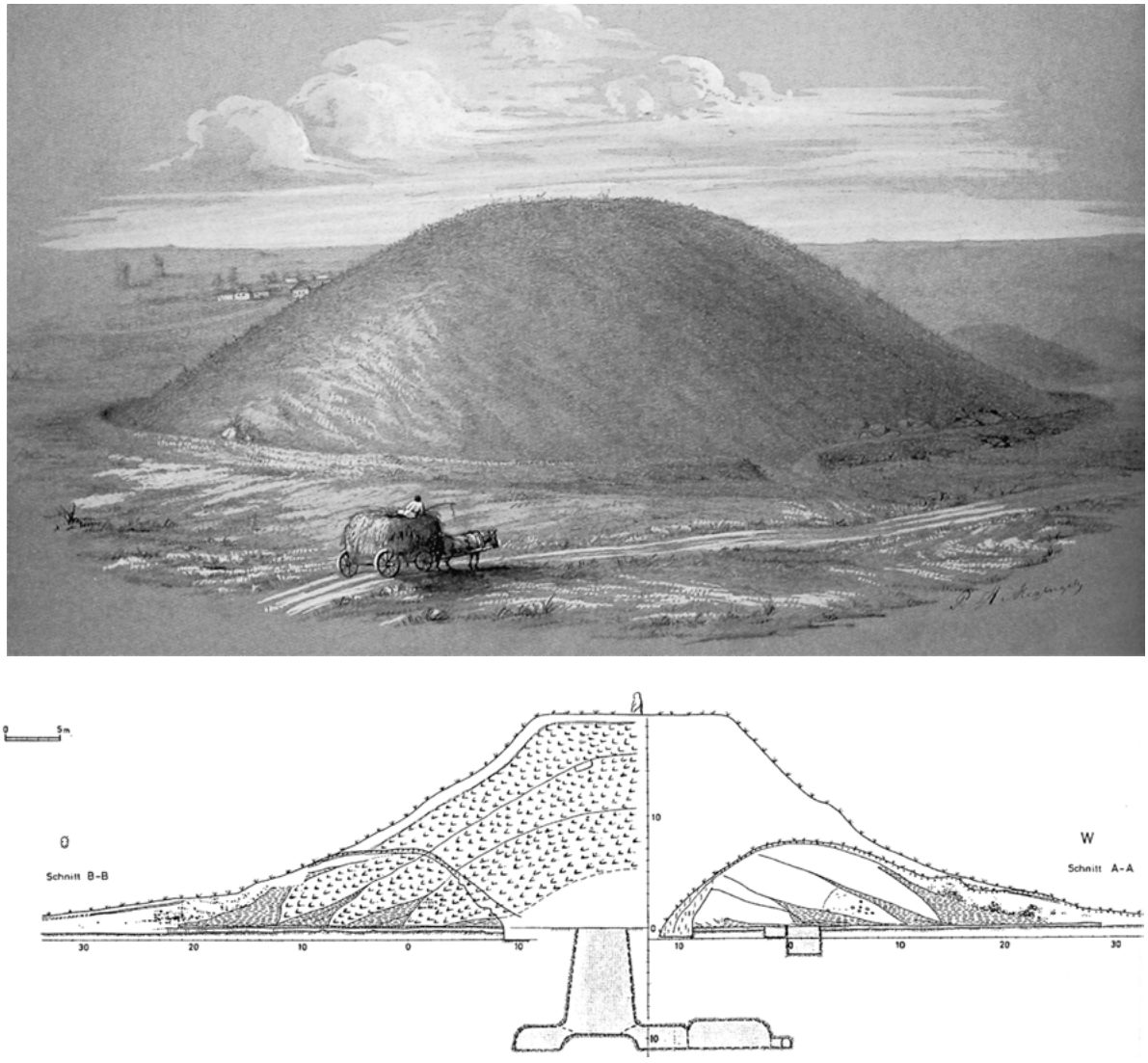


Fig. 2.11 | (a) Engraving of the kurgan at Alexandropol' before the start of the excavations in the middle of the 19th century (after Alekseev, 2007, fig. 10).
(b) Schematic profile of the kurgan Certomlyk. The kurgan measures 115 m to 120 m in diameter and has a height of 20 m (after Parzinger, 2007, fig. 4).

2007, 148). Archaeological investigation of the Pazyryk culture began in the early 20th century when M. P. Gryaznov and S. I. Rudenko excavated the first so-called 'frozen kurgans'. Important sites of 'frozen kurgans' are Katanda, Pazyryk and kurgan groups located on the Ukok plateau (Molodin/Polos'mak, 2007, 142; Parzinger, 2010, 60). Typically, the burial mounds of the 'common population' of the Pazyryk culture measure 3 m to 25 m in diameter and 1 m in height. The small mounds are sometimes surrounded by circular stone fences. The dead were buried in log coffins or stone boxes and oriented to the east or, less frequently, to the west. Single, double and group burials occur. The dead wore highly ornamented costumes. Frequently found burial objects include weapons, decorated belts, ornamented wooden vessels, sometimes containing food, and further wooden objects. Horses were buried with har-

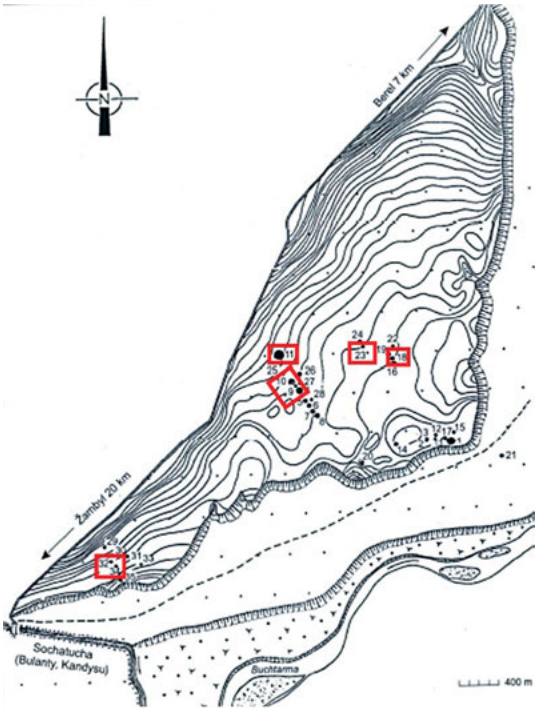


Fig. 2.12 | Distribution of the burial mounds at Berel'. Samples were taken from circled kurgans (modified after Samashev et al., 2002, fig. 2).

nesses and were sometimes highly ornamented with plaques and pendants (Bokovenko, 1995b, 288–289). The graves of the 'elite' of the Pazyryk culture were extraordinarily furnished and although the kurgans were larger, their dimensions were still smaller when compared to the North Pontic ones (Parzinger, 2004, 45–46; Parzinger, 2009, 20–21). The extraordinary preservation of the 'ice mummies' allowed the discovery of one of the most distinct characteristics of the Pazyryk culture, namely the tattooed mummies that were re-filled with organic material (grasses) after the removal of the intestines (Barkova, 2007, 121–123). The excavation of dozens of burial mounds near the modern village of Berel', broadened the knowledge about the Pazyryk culture. Berel' is located in a high mountain valley and contains a group of more than 70 burial mounds of varying dimensions arranged in lines or small groups (Fig. 2.12). Altogether four groups of kurgans can be distinguished. Due to the location of the site in a valley approximately 1120 m above sea level, the burial mounds are perennially partly frozen leading to an extraordinary preservation of the organic material (Samašev, 2007, 132; Keyser et al., 2005, 203). According to one of the excavators most of the kurgans date to the late phase of the Pazyryk culture (Samašev, 2007, 136). The kurgans are oval or round in shape, of varying dimensions and burial furnishings that represent different social classes of the community (Samašev, 2007, 136). A general description of the characteristic kurgan architecture at Berel' is given by kurgan 11 (Fig. 2.13) (see Samašev et al., 2002, 249–270; Keyser et al., 2005, 203; Samašev, 2007, 132–134): This burial mound is the second largest after kurgan 1, with a diameter of 23 m. A rectangular trench with a depth of more than 6 m encircles the mound. The wooden burial chamber contained a wooden sarcophagus containing the primary grave of a man who wore a wig with tails and who bore the signs of an unfinished trepanation, perhaps due to an operation on a battle wound. This primary burial was accompanied by the grave of a woman. Close genetic congruities suggest that the two humans were most probably mother and son. The heads of both skeletons were placed on wooden pillow constructions (Samashev et al., 2000, 24). At the northern wall of the funeral chamber 13 horses were arranged in two tiers, with six animals on one level and seven ani-

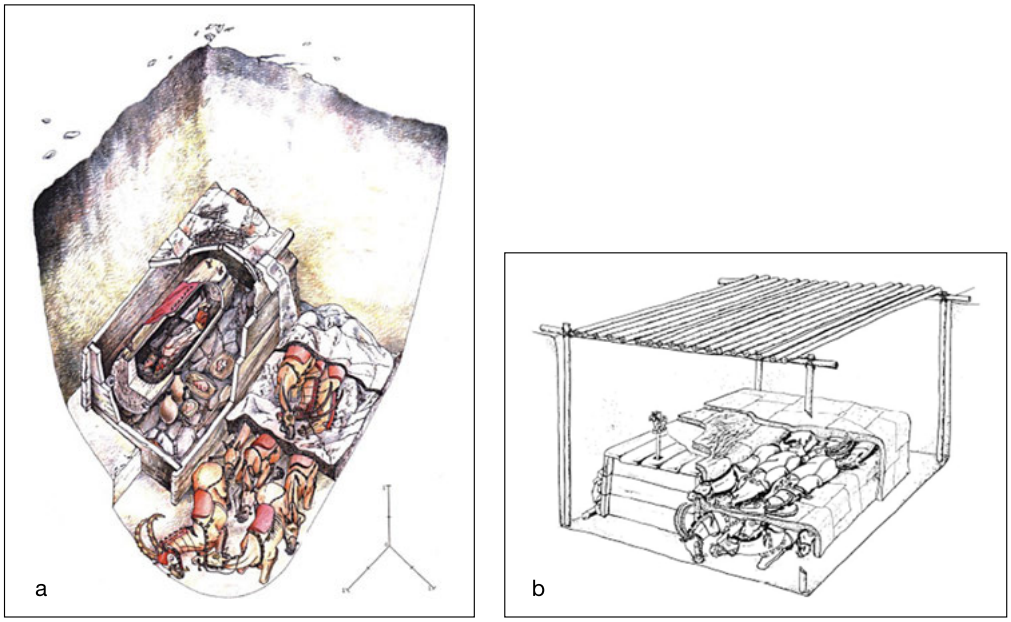


Fig. 2.13 | Reconstruction of the burial chamber in Berel' kurgan 11 (fig. 2.13a: after Samashev et al., 2002, 27; fig. 2.13b: after Samashev et al., 2006, fig. 17).

mals on the second level. They were bridled and saddled and wore highly ornamented adornment with floral and faunal motifs. Zoomorphic and genetic analysis of the horses showed that the animals were all male, ranged between 8 and 20 years of age and that there was no similarity of ornamentation or common mtDNA haplotypes (Keyser et al., 2005, 204–209). The large number of exquisite burial objects and clothes, together with the number of horse sacrifices, indicate the high social rank of the deceased. The Pazyryk kurgans show the presence of two distinct horse types; highly ornamented 'race horses' and small Mongolian horses of local origin that were mainly draught animals (Barkova, 2007, 130).

Settlement sites of the Pazyryk culture are unknown, but some insights into the economy and subsistence are given by the burial objects and the horse depositions, which suggest that the Pazyryk culture were nomadic herding horsemen (cf. Barkova, 2007, 123–126). Aside from herbivore products and wild plants, the chemical analysis of mummy hair on the Ukok Plateau suggested that the diet also included high amounts of fish. Trade connections were probably both small-scale and wide-ranging, since the gold from finds in the graves on the Ukok Plateau derived from local sources (Molodin/Polos'mak, 2007, 146), but the burial objects and traditions also reveal connections to the territories of modern Iran and China (Parzinger, 2004, 45, 55).

2.2 Methodological background

2.2.1 The application of isotope analysis

The identification of prehistoric human mobility and migration is traditionally approached in archaeology by the definition of cultures, their distributions, their borders and the determination of outliers relative to this. In later periods historic sources can also be consulted. The reconstruction of palaeodiet

and subsistence is commonly approached in archaeological research through the analysis of archaeological objects that can be connected to hunting, gathering, animal husbandry, fishing and agricultural activities, and by the anthropological analysis of skeletal remains. The combination of archaeological and scientific methods gives a deeper understanding of prehistoric societies. Scientific approaches used to answer questions of movements and diet in the archaeological record are aDNA, trace element, lipid and isotope analyses (cf. Tütken, 2010, 33). This study focuses on the application of isotope analyses.

2.2.1.1 Mobility in archaeology and the application of strontium and oxygen isotope analyses

The application of $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses is becoming more and more common in archaeological research to investigate human and faunal mobility and to a lesser extent also hydrogen ($\delta^{2}H$), sulphur ($\delta^{34}S$) and lead ($^{208}Pb/^{206}Pb$, $^{207}Pb/^{206}Pb$). The potential of oxygen and strontium isotope analyses in archaeological research was discovered almost 30 years ago in the mid 1980s. Principally, $\delta^{18}O$ values were used as climate proxies for studies of climate reconstruction and climate change, when Longinelli (1984) and Luz (1984) independently recognized the potential of oxygen isotope ratios in modern and fossil animal and human remains to reconstruct drinking water sources. Average air temperature can be calculated using the $\delta^{18}O$ values of bones and of drinking water due to the positive correlation between average air temperature and the $\delta^{18}O$ in precipitation (e.g. Dansgaard, 1964; Rozanski et al., 1993; Longinelli, 1984; Stephan, 1999; Tütken et al., 2004). The initial studies did not principally concern archaeological questions but instead looked at faunal diet, physiology and water uptake, e.g. studies on Australian kangaroos (Ayliffe/Chivas, 1990), on fossil equids (Bryant et al., 1994; Bryant et al., 1996a, b), on African Pleistocene hominids (Bocherens et al., 1996), on the tooth oxygen isotope composition in herbivores (Kohn et al., 1996) and on oxygen isotopes in enamel carbonate (Sponheimer/Lee-Thorp, 1999). Further studies concerning the identification of places of origin and the distinction of foreigners versus locals were only published from the late 1990s onwards, e.g. the isotopic investigation of the geographical origin of individuals from Teotihuacan and Monte Alban, Mexico (White et al., 1998; 2001; 2002; Price et al., 2010) and the human migration in the Dakhleh Oasis, Egypt (Dupras et al., 2001). The origin of single individuals was subject to studies like the investigation of the Ötzi mummy (Hoogewerff et al., 2001; Kutschera/Müller, 2003; Müller et al., 2003, also an example of a multi-isotope approach). Another focus concentrated on the animal management of prehistoric herders (e.g. Balasse et al., 2002; Henton et al., 2010; Balasse et al., 2012), on seasonal birth determination and weaning (Balasse et al., 2003; Balasse/Tresset, 2002; Balasse/Tresset, 2007) and on seasonal supplementary feeding (Balasse et al., 2006) of domestic animals. Other studies targeted single methodological aspects like the exploration of human infant feeding behaviour and the impact of breast milk on the oxygen isotopic signal (e.g. Wright/Schwarcz, 1998; White et al., 2000) or the geographic distribution patterns of biologically available $\delta^{18}O$, $^{87}Sr/^{86}Sr$ and $\delta^{13}C$ isotopes (Bentley/Knipper, 2005).

Almost concurrently to the first studies using oxygen isotope analysis Ericson (1981; 1985) recognised the potential of strontium isotope analysis for archaeology in proposing to analyse human and faunal hard tissues such as tooth and bone to find answers to questions of mobility and migration. The origin of human individuals first became the focus of attention in a study of the origin of soldiers of the War in 1812 in Snake Hill, USA (Schwarcz et al., 1991). In the following years the number of studies applying strontium isotope analysis grew steadily. They concerned the development of the application of the methods to archaeological research questions as well as small studies that advanced to studies

including much bigger sample sizes over the last two decades. While the first studies in the 1990s investigated the migration of human individuals and groups by looking at the skeletal remains only, new research questions arose and the method was increasingly refined and developed. It became clear that the isotopic characterisation of the geographical surrounding area needed to be included. The growing number of studies in the first years of the third millennium will only be mentioned selectively since the research history of $^{87}Sr/^{86}Sr$ applications has been excellently discussed in detail by C. Knipper (2004, 592–594; 2011, 188–192). In general, there are studies spanning almost all time periods and taking place in widespread locations all over the world, but while most of the studies concentrate on settled communities, mobile societies are often ignored. In Central Europe, the Neolithic and particularly the *Linearbandkeramik* (e.g. Price et al., 2001; Bentley et al., 2002; Bentley et al., 2003; Bickle/Hofmann, 2007; Nehlich et al., 2009; Knipper/Price, 2010; Bentley et al., 2012; Bickle et al., 2011; Bickle/Whittle, 2013), but also the Bell Beaker period (e.g. Grupe et al., 1997; Heyd et al., 2002/2003; Price et al., 2004), have attracted special attention. Furthermore, later periods such as Late Roman (Schweissing/Grupe, 2003a; 2003b; Schweissing, 2004) and early medieval cemeteries (Tütken et al., 2008; Knipper et al., 2012; Maurer et al., 2012) have also been investigated. In some regions, e.g. Saxony-Anhalt in Germany (e.g. Haak et al., 2008; 2010; de Jong et al., 2010), ongoing diachronic projects have enabled intense isotopic investigation of a wide area. In other parts of Europe $^{87}Sr/^{86}Sr$ and increasingly multi-isotope studies were applied on human mobility in different time periods, in Britain (e.g. Budd et al., 2002; 2003; 2004; Montgomery et al., 2005; Evans et al., 2006) and Scandinavia (e.g. Price, 2006; Price et al., 2007b).

There are also an enormous number of studies located in other continents. Stable isotope studies focused on the Palaeolithic sites in southern Africa (e.g. a combined Sr, C, N isotope study by Sealy et al., 1995), on Palaeolithic to Neolithic communities in Libya (Tafuri et al., 2006) and on the Nile valley during the New Kingdom period (Buzon et al., 2007). The Tiwanaku civilisation in South America was subject to multi-isotope studies aiming to reconstruct dietary and mobility patterns (Knudson et al., 2004; 2005; 2007; Knudson/Price, 2007). The mobility of the Inca and the Pre-Columbian period in South America (Slovak et al., 2009; Turner et al., 2009) as well as the Maya societies in Mesoamerica (Price et al., 2000; Hodell et al., 2004; Wright, 2005; most recently White et al., 2007) were subject to numerous studies. Projects in North America looked at the investigation of human mobility at the Grasshopper Pueblo in Arizona (Ezzo et al., 1997; Ezzo/Price, 2002) and in Aztalan in Wisconsin (Price et al., 2007a). Sr isotope studies in Asia are less numerous so far, e.g. the exploration of Neolithic mobility on the island of Borneo (Valentine et al., 2008).

All these studies (and many more) examined the reconstruction of human migration and mobility in settled societies, while due to obvious difficulties fewer Sr and O isotope studies have been applied to non-settled communities. Analysis of the mobility of human individuals buried in a Bronze Age cemetery near Lake Baikal in Siberia (Haverkort et al., 2008) and in megalithic tombs in southwest Sweden (Sjögren et al., 2009) are two examples.

As isotope analysis is more routinely included in research projects, there is a tendency towards the combination of strontium and oxygen isotope analyses and towards multi-isotopic analysis (e.g. Chenery et al., 2010; 2011). While Sr isotope analysis is extensively used to answer archaeological questions about human mobility and diet, less studies have focused on archaeological faunal material (see Knipper, 2011, 191–192 for a detailed overview). The teeth of archaeological fauna are commonly used to determine the biologically available strontium (see Price et al., 1994; Beard/Johnson, 2000 and Bentley, 2006 for discussion), but faunal mobility in pre- and protohistory has not yet been much investigated. Studies based in Central Europe have attempted to reconstruct the mobility patterns of Palaeo-

lithic wild animals (Price et al., 2008) and of domestic animal husbandry in and around Iron Age hillfort sites, in which the existence of different animal mobility patterns and animal imports have been proven (Schatz/Stephan, 2008; Stephan et al., 2012). Archaeological pig teeth were analysed from several sites in southern Germany by Bentley and Knipper (2005), who were able to identify an upland-lowland variation in the $^{87}Sr/^{86}Sr$, $\delta^{18}O$ and $\delta^{13}C$ isotope ratios in the animal teeth. Moreover, cattle husbandry in the *Linearbandkeramik* in southern Germany was subject to an intense study (Knipper, 2010; 2011). Another extensive study focused on animal husbandry strategies at two sites in Early and High Middle Ages England and showed varying strategies ranging from local animal housing to mobile herding systems (Evans/Tatham, 2004; Evans et al., 2007). Studies on other continents have investigated the seasonal movements of sheep and cattle in South Africa (Balasse et al., 2002, see above) and of late Pleistocene mammals (Hoppe et al., 1999; Hoppe et al., 2004). Since the turn of the millennium, sequential analysis of tooth enamel has been introduced and this offers additional information about the time of movement, like seasonal mobility for example (e.g. the studies of M. Balasse, E. Henton and C. Knipper).

Considering the large number of mobility studies it is interesting to note that only a very small number of strontium isotope projects focuses on the regions in Western Eurasia and Eastern Europe that comprise the study area. To date, strontium isotope studies in the study area have only been applied to the Neolithic and Copper Age transition in Eastern Hungary (Giblin, 2004; Giblin et al., 2009; Hoekman-Sites/Giblin, 2012 in combination with $\delta^{13}C$ and $\delta^{15}N$) and the Megalithic tomb burials just outside the study area in the Caucasus (Trifonov et al., 2012). Oxygen isotope studies on animals have been undertaken in different parts of Russia (Iacumin et al., 2004 a, b), on a Greek colonial population in Bulgaria (Keenleyside et al., 2011) and on horses in the Mongolian Altai Mountains (Bendrey et al., in press).

2.2.1.2 Palaeodiet and the application of carbon and nitrogen isotope analysis

The traditional archaeological approach to identify questions on diet and subsistence strategies is to study the archaeological material in burials and settlements, objects such as grinding stones and tools for agricultural activities and food remains or crusts on pottery. In addition, disciplines like palaeobotany (imprints of grains) and pollen analysis (cultivated crops) are applied. The chemical analysis of ceramic shards can also add information about diet in archaeological communities. Other options include the application of light stable isotope analysis, namely $\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$ analyses, as well as trace element analyses. The most commonly used techniques in the reconstruction of past human diet are $\delta^{13}C$ and $\delta^{15}N$ analyses.

While stable isotope analysis in general has been applied to scientific investigations since the beginning of the 20th century, it has only been used to answer archaeological questions since the latter second half of the century. M. A. Katzenberg noted that archaeologists were 'relative latecomers to the study of stable isotope variation of the elements, with the exception of carbon' (Katzenberg, 2008, 415). Following on from the important developments in geochemistry and biochemistry in understanding of isotope variations in the geosphere and biosphere that took place in the 1950s and 1960s, stable isotope analysis, i.e. carbon and, slightly later nitrogen isotope analysis, was first applied to palaeodietary questions in the 1970s (Vogel/van der Merwe, 1977; DeNiro/Epstein, 1978; 1981; van der Merwe/Vogel, 1978). These studies were followed by the investigation of trophic level change and marine versus terrestrial feeding in respect to $\delta^{15}N$ (Schoeninger/DeNiro, 1984) and by the study of pre- and protohistoric groups in east

and south Africa with a subsistence based on animal husbandry and plant cultivation (e.g. Ambrose, 1986; Ambrose/DeNiro, 1986; 1987).

In the last decade particularly, the number of palaeodietary studies applying carbon and nitrogen isotope analysis have increased significantly and the methods have subsequently been applied in many different contexts. Since a good overview of the range of studies is given in Katzenberg (2008, 413–415 with older literature) only a selection of exemplary studies will be mentioned here. One prominent field was the characterisation of the hunter-gatherer strategies of Upper Palaeolithic and Neanderthal specimens (e.g. Drucker/Bocherens, 2004; Richards et al., 2000; Stevens et al., 2010). Studies revealed, for example, a broad spectrum economy with a reliance on marine and freshwater resources in Upper Palaeolithic anatomically modern humans (Richards et al., 2001). Later periods have also been in the focus of studies, for example Neolithic societies in Central Europe (e.g. Dürrwächter et al., 2003; Bickle/Whittle, 2013), and Roman populations in Italy (e.g. Prowse et al., 2004; Prowse et al., 2005) and Britain (Richards et al., 1998; Fuller et al., 2006; Müldner/Richards, 2007). In Northern Europe, the coast-inland mobility in the Danish Mesolithic and Neolithic (Fischer et al., 2007) and dietary patterns in relation to social structures in Medieval Sweden (Kjellström et al., 2009) were explored. The investigation of a correlation between diet and social hierarchy was also subject to other studies in the last decade (e.g. Müldner/Richards, 2005; Jay/Richards, 2006). Mobility in correlation with climatic conditions and kinship systems were additionally explored (e.g. Tafuri et al., 2006). In contrast to earlier studies, when palaeodietary investigations were based on small sample sizes of humans, recent studies have demonstrated that a significant number of contemporaneous animal species form the basis for a confident reconstruction of human palaeodiet due to intra-population variability deriving from environmental and climatic influences (Stevens et al., 2010, 52). Today, carbon and nitrogen isotope analysis is almost routinely used to reconstruct past human diet. Furthermore, their potential for the identification of immigrants and movement patterns was realised and is increasingly exploited.

The first and most extensive stable isotope studies in the study region were carried out by M. C. Lillie and colleagues (e.g. Lillie, 1998; Lillie/Richards, 2000; Lillie et al., 2003; Lillie/Jacobs, 2006; Lillie et al., 2009, Lillie/Budd, 2011; Lillie et al., 2011; see Lillie et al., 2012), who worked on the palaeodietary reconstruction of Epipalaeolithic to Eneolithic skeletons from the Lower and Middle Dnieper basin in Ukraine. They extended their data set continuously and have so far assessed a data set of 113 skeletons from seven burial sites for $\delta^{13}C$ and $\delta^{15}N$ analysis (Lillie et al., 2012). N. I. Shishlina and further authors published results from a sequence of carbon and nitrogen studies in multiple articles (van der Plicht et al., 2006; Shishlina, 2008; Shishlina et al., 2007; 2009; 2012). They concentrated on the reconstruction of a subsistence economy and diet of the Eneolithic and Bronze Age people in the Caspian steppes and the North Caucasus region. One of their major observations was the significant role of freshwater resources as well as the relation of stable isotopes and climate. In her PhD thesis K. Privat (2004) studied palaeodiet at different prehistoric sites in Russia and Ukraine. Her results were partly published in O'Connell et al. (2003) and Privat et al. (2007). To date N. Honch and colleagues are the only ones to conduct palaeodiet research using stable isotopes in the West Pontic region, in their investigation of dietary patterns near the Bulgarian Black Sea coast in the Copper Age (Honch et al., 2006).

Outside the study region, several other palaeodietary studies have been conducted at the Iron Gate (see Nehlich et al., 2010 with an overview of earlier publications), in the Caucasus Mountains (Higham et al., 2010; Hollund et al., 2010) and in the area surrounding Lake Baikal in Siberia (Katzenberg/Weber, 1999; Katzenberg et al., 2009; Weber et al., 2011). As with Shishlina, Hollund and colleagues found that stable isotopes related mainly to geographic locations and climate variations.

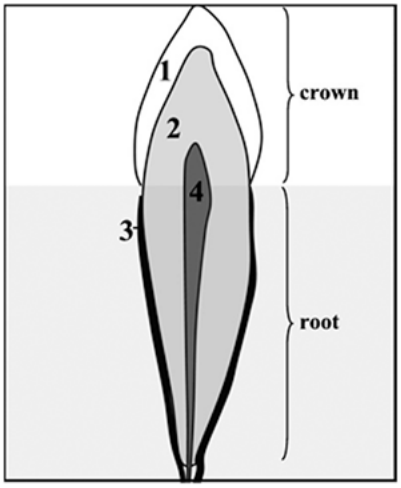


Fig. 2.14 | Longitudinal tooth section (modified after Montgomery, 2002, 47 fig. 3.1; cf. also Reitemeier et al., 2006, 70 fig. 3.3): 1 enamel, 2 dentine, 3 cementum, 4 pulp cavity.

2.2.2 Tooth and bone as sample materials and information archives

Conclusions in respect to human and faunal ways of life and nutrition can be drawn from the elemental and isotopic composition of their tooth and bone (e.g. Ambrose, 1993). Since the isotope ratios in these tissues are compared to estimated ratios of the sample sites, one essential condition for an interpretation of data deriving from stable isotope analysis is to understand the human and faunal hard tissues that have been sampled, their formation and processes that may alter them (Tütken, 2010).

The objective of investigations into mobility and migration is to reconstruct the places of origin of human and faunal individuals. In contrast to bone, human tooth enamel does not undergo periodic replacement or re-modelling during the lifetime of an individual and is therefore well suited to establish where that individual was during its infancy (Hillson, 1996, 148–149).

The mammalian tooth consists of a root and a crown (Fig. 2.14). The root is composed of the pulp cavity in the innermost part, with a thick layer of dentine and a thin layer of cementum above. The crown is the visible part of the tooth and is formed by a core of dentine overlaid by a layer of enamel. All tissues, enamel, dentine and cementum, are organic composites (Hillson, 1996, 8). Cementum, dentine and enamel are 'composed almost entirely of calcium phosphates from the apatite family of minerals, the bulk of it hydroxylapatite' (Hillson, 1996, 217). Hydroxylapatite is composed mainly of calcium and phosphorus (38 % and 19 % respectively) but also elements such as strontium (Schweissing, 2004, 6). Both enamel and dentine formation starts from the crown and continues towards the root, but the formation of dentine starts a little earlier than that of enamel (Reitemeier et al., 2006, 72).

Tooth enamel is non-cellular and avascular. It is composed of 95 to 98 % of inorganic material and 2 to 3 % of organic material and water (Buddecke, 1981, 7). The enamel coat on the tooth crown is typically 1 to 2 mm thick (White/Folkens, 2005, 135; Hillson, 1996, 148). Tooth enamel, as an acellular tissue, does not undergo remodelling after formation and therefore retains the isotopic signal of infancy (Knipper, 2004, 602–603).

Dentine underlies the enamel layer in mammalian teeth and extends into the tooth socket in the jaw. Dentine has no vascular supply but is supported by the vascular system in the pulp. Consisting of

Table 2.3 | Mineralization of human tooth enamel (after Schweissing, 2004, 16 table 2).

item	begin mineralization	end mineralization
incisors	3–4 months (I2 maxilla 10–12 months)	3.3–5.9 years
canines	4–5 months	4.0–5.8 months
premolar 1	18–24 months	5–7 years
premolar 2	24–30 months	6.1–7.2 years
molar 1	7–8 fetal months	2.1–3.6 years
molar 2	30–36 months	6.2–7.4 years
molar 3	7–10 years	12–13.7 years

approximately 20% organic, 10% water and 70% inorganic material, dentine is much softer than enamel. The mineral phase of dentine builds hydroxylapatite (Frank/Nalbandian, 1989, 175–176). Dentine formation occurs in two phases: organic matrix secretion followed by mineralization (White/Folkens, 2005, 135; Hillson, 1996, 184). Three forms of dentine can be distinguished with different formation periods: primary dentine is formed during and up to the end of root formation, then secondary dentine is formed after root formation is complete, along the pulp cavity. Tertiary dentine is a reactionary or reparative form of dentine that occurs around tooth fractures in the tooth (Frank/Nalbandian, 1989, 177). Dentine forms mostly during childhood: primary dentine is laid down at the time of initial formation of the tooth. Later in life, a small amount of secondary dentine is added, mostly around the edges of the pulp cavity. Tertiary dentine may also be deposited in response to injury or decay. Primary dentine does not undergo remodelling processes; hence the isotopic composition of childhood remains essentially the same (Lowenstam/Weiner, 1989, 147; Sealy et al., 1995, 290). Dentine that is formed in later stages of life, i.e. secondary and tertiary dentine, on the other hand, displays a mixture of childhood and adulthood composition (Knipper, 2004, 606).

Humans have deciduous and permanent dentition. The deciduous teeth are already partly-formed at the time of birth and erupt within the first two years of life. Permanent dentition also starts its formation before birth and gradually replaces the deciduous dentition between the ages of five and twenty (Hillson, 1996, 6; White/Folkens, 2005, 131). Permanent dentition, also known as secondary teeth, as its name implies, lasts for most of the adult's life. This permanent dentition is composed of four incisors, two canines, four premolars and six molars symmetrically arranged in each of the lower jaw (the mandible) and the upper jaw (the maxilla).

The deciduous teeth form sequentially: the first incisors starting about 14 to 16 weeks after fertilization, followed by the first molars at 15 weeks, the second incisors at 16 to 18 weeks, the canines at 17 to 19 weeks, and finally, the second molars start mineralizing 18 to 19 weeks after fertilization (Hillson, 1996, 124 table 5.2). Permanent dentition (Table 2.3) also starts its formation before birth with the first molar. Postnatally, the permanent incisors start growing at about 3 to 4 months of age. Within the first year, the first canine and the second incisor also start growing. In the second and third year of life, both premolars and the second molar begin to form. While the molar crowns of first molars have finished mineralizing at 3 years of age, the completion of the permanent dentition is very variable: incisors at 4 to 5 years old, canines and first premolars at 6 years, second premolars and second molars at 7 years. The enamel of the first molar mineralizes from 0 to 3 years, followed by the premolars between 2 and 6 years

Table 2.4 | Tooth enamel mineralization in modern equids (after Hoppe et al., 2004, 358, table 2).

tooth	begin mineralization (in months)	end mineralization (in months)
premolar 2	13 ± 1	31 ± 2
premolar 3	14 ± 1	36 ± 3
premolar 4	19 ± 3	51 ± 2
molar 1	0.5 ± 1	23 ± 3
molar 2	7 ± 1.5	37 ± 3
molar 3	21 ± 3	55 ± 2

of age. While the third molar starts formation around 7 to 13 years and the crown is completed by 12 to 16 years, the mineralization takes place between 9 and 12 years (Hillson, 1996, 124–125; Wright/Schwarcz, 1998, 5).

For the present study samples were taken for analysis from both human and faunal teeth. Horse and cattle teeth were the only faunal samples selected for analysis of geographic movement, while samples from other animals were taken as comparison material. Hence, only horse and cattle dentition will be discussed in detail. As horses and cattle are also mammals, the development of their teeth is essentially the same as that of humans, described above. There are some significant differences however, one of them being that herbivores have alternating layers of enamel and dentine that mineralize sequentially through life. Another difference is the thickness of the cementum layer, which is highly variable at different ages (Hillson, 1996, 198–199).

Some of the samples selected derive from horses (from the site of Berel', Kazakhstan). The timing of tooth mineralization and eruption is well understood for modern equids (Table 2.4) (Levine, 1982; Bryant et al., 1996a; Hoppe et al., 2004). While deciduous teeth have already erupted at the time of birth, permanent teeth erupt in the following sequence: first molars (M1) erupt between 7 and 12 months, followed by second molars (M2) between 16 and 24 months. At the age of 2.5 to 3.5 years, the second and third premolars (P2, P3) erupt, whereas the fourth premolar (P4) and third molars (M3) erupt between 3 and 5 years of age (in Bryant et al., 1996a, 78; slightly differing time spans are given in Hoppe et al., 2004, 357).

The mineralization of enamel in horses starts up to a year or several months before tooth eruption, around the first 55 months of the animal's lifetime, and continues after eruption. Thus, a transverse enamel section represents several months. The maturation of horse tooth enamel continues for 5 months (Hoppe et al., 2004, 355; Kohn, 2004, 403). The molars represent an overlapping record of the entire mineralization period. As horse teeth are continuously worn down, and mineralization occurs from the bottom, the older dentine and enamel near the crown will be progressively worn away and the available amount of tooth depends on the age of the horse and the coarseness of its fodder presumably (Bendrey et al., 2009, 142). Post-eruptive wear leads to enamel-loss and hence to a reduction of the represented length of time of the tooth (Pellegrini et al., 2008, 1717). The sequence of tooth eruption in modern and fossil horses is the same, but the time of tooth eruption is much more uncertain in fossil horses (Bryant et al., 1996b, 399). Bryant et al. (1996a) found that mineralization in Miocene horses occurred earlier than in modern horses (Bryant et al., 1996a, 83), but similar patterns between Bronze Age and modern horses can be assumed.

A single sample represents average values over the time interval of maturation, which in horses takes 3 or 4 months (Higgins/MacFadden, 2004, 344). According to Hoppe et al. (2004) LM1, LM2, LP2 and LP3 grow at a rate of approximately 3.5 to 4 cm per year. The third molar of horses may contain an isotopic signal of up to three years (Higgins/McFadden, 2004, 338; Hoppe et al., 2004, 355).

Since foals have only minimal water uptake before weaning, which occurs between 9 and 15 months of age, the teeth that mineralize before weaning reflect the $\delta^{18}O$ of the mare rather than that of the foal (Bryant et al., 1996a, 78; Bryant et al., 1996b, 399). The ^{18}O in milk is enriched by 1 to 2 ‰ in comparison to water (White et al., 2004, 233), which must be taken into consideration when analysing results from unweaned animals. The $\delta^{18}O$ of individual teeth vary as mineralization occurs over periods of seasonal fluctuations and this must be taken into account when interpreting the results (Bryant et al., 1996a, 84–85).

Bone is a composite tissue that consists of 25 to 30 % organic material, 50 % inorganic material and 20 to 25 % water. The organic matrix of bone is collagen. The inorganic component of bone consists of hydroxylapatite, a calcium phosphate [$Ca_{10}(PO_4)_6(OH)_2$], which includes a number of trace elements, such as strontium (Schweissing, 2004, 4; Katzenberg, 2008, 416; White/Folkens, 2005, 25; Tütken, 2010, 34).

Unlike tooth enamel, bone undergoes a constant structural turnover and therefore exchange in trace elements during the lifetime of an individual. The isotopic composition of bone reflects long-term averages of the last years of life. The turnover time is dependent on the specific bone and takes several years or decades. While the turnover rate for cortical bone is 2 to 3 %, the rate for trabecular bone is 24 % per year. The metacarpal and metatarsal bones, tibia and ulna have slow turnover rates, while faster turnover rates of 20 to 30 years are valid for ribs and pelvic bones (Knipper, 2004, 610–615; Schweissing, 2004, 17; Sjögren et al., 2009, 87; Tütken, 2010, 35).

Diagenetic processes can affect the isotopic composition of archaeological tooth and bone. The degree of diagenetic alteration depends mainly on the burial environment, with the age of the skeletal remains being of minor importance. Diagenetic alteration can take place over a few decades but might not happen at all (Tütken et al., 2004, 92; Tütken, 2003 with an overview on the diagenesis of bones). The results of isotopic analysis can only be properly interpreted after due consideration of any potential diagenetic alteration of the sampled tissues.

In terms of $^{87}Sr/^{86}Sr$ analysis diagenetic alteration of body tissue is a severe issue. Enamel is the body tissue that is most resistant to diagenetic changes. The larger apatite crystallites in tooth enamel mean that the mineral structure is less porous and has a smaller organic component, which improves its resistance to diagenetic alteration compared to dentine and bone and enamel is therefore preferred for isotopic analysis (Tütken et al., 2004, 92). Though unaffected by most burial conditions, extremely acidic sediments are likely to alter tooth enamel possibly even dissolve it completely (Hillson, 1996, 181, 224). Archaeological dentine is frequently softened and brittle (Hillson, 1996, 196). The porosity of dentine and bone enables the exchange of minerals with the surrounding burial environment, making them rather less suitable for isotopic analysis (Hillson, 1996, 206; Budd et al., 2000), but useful as baseline proxies for the local burial environment, with the caveat that the isotopic composition of the burial environment does not necessarily equate to the biologically available strontium in the area surrounding the sample site.

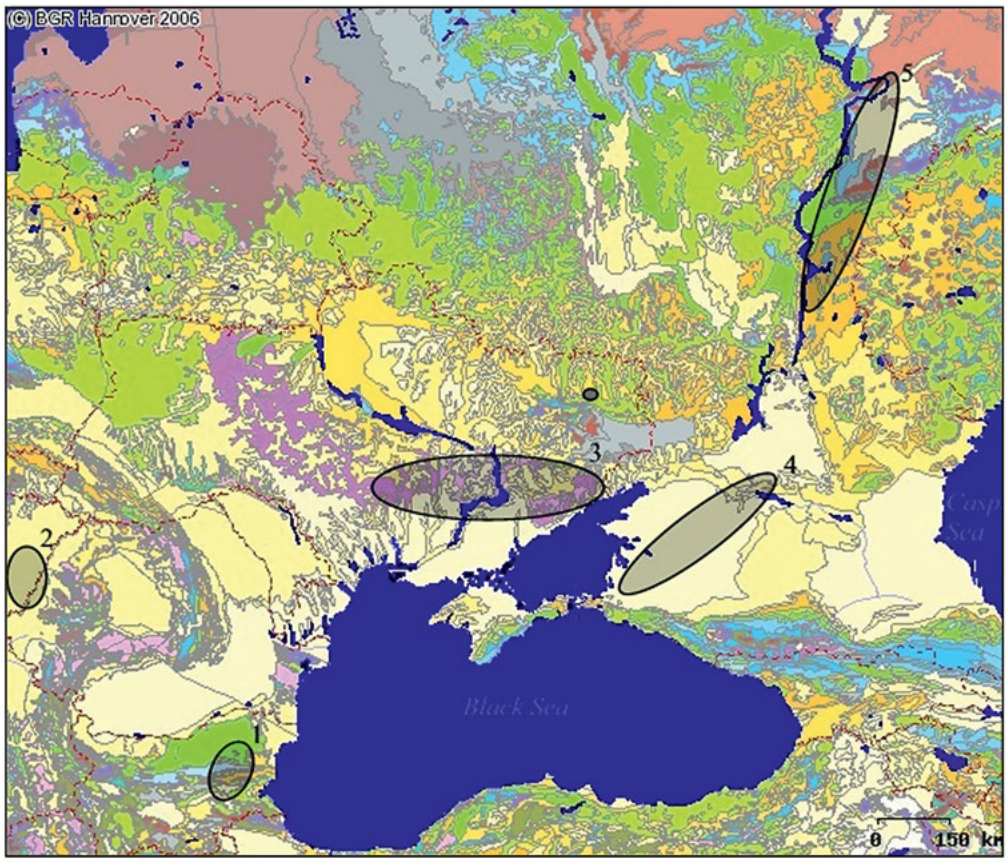


Fig. 2.15 | Geological map of the North Pontic and its adjacent areas (modified after Asch, 2005). Cenozoic (yellowish), Mesozoic (green, blue, purple), Palaeozoic (rust brown, grey, turquoise, olive), Precambrian (pink). Sample regions (1: Bulgaria, 2: Hungary, 3: Ukraine, 4: South Russia, 5: Volga region, Russia) are circled.

2.2.3 Geology and ecology in the study region with regard to isotope analysis

$^{87}/^{86}Sr$ ratios mainly reflect the geological bedrock that underlies the sample sites, necessitating a brief introduction of the geology in the study region (Fig. 2.15). An explanation of the way that the underlying geology translates into Sr isotope ratios will follow in chapter 4.3. The study region in Bulgaria comprises varying geology with Cenozoic sediments on the plains and Mesozoic to Precambrian bedrock in the hills and mountainous areas. The study area in Hungary lies in the eastern part of the Great Hungarian Plain east of the river Tisza. While the plain is filled with young sediments of the Tertiary and Quaternary period; fluvial sands, drifting sands, gravel, loess and clays (Trunkó, 1996, 125), the surrounding mountain ranges are dominated by Mesozoic, Palaeozoic and Precambrian rocks (Trunkó, 1969, 1, 107). The North Pontic region is slightly less geologically diverse, with a combination of Cenozoic sediments on the plains and outcrops of Precambrian rocks in the river valleys. Iron ore deposits originating in the Proterozoic are dispersed in a belt north of the modern town of Krivoy Rog, and manganese ores are mined around the city of Nikopol' (Naliwkin, 1959, 14–20). The study site in Eastern Ukraine is located in an area of mixed Cenozoic and Mesozoic, particularly Cretaceous, geology. There are widespread outcrops of Palaeozoic rocks to the south. The predominant geology both in

Fig. 2.16 | Distribution of loess in the study area: Loess > 5 m (orange), loess < 2 m (light orange), loess and loess derivates in fragmentary distribution (diagonal striped), sandy loess (yellow), Aeolian sands (dotted), alluvial loess (green) (after Fink et al., 1977). Sample regions (1: Bulgaria, 2: Hungary, 3: Ukraine, 4: South Russia, 5: Volga region, Russia) are circled.

the Kuban and the northwest Caspian region is again Cenozoic. The study sites along the Lower and Middle Volga also lie on chiefly Cenozoic sediments, mixed with Mesozoic, especially Cretaceous, but also Jurassic and Triassic, and Palaeozoic geology (Naliwkin, 1959, 21). Not shown on the map are the Altai Mountains which are geologically diverse comprising rocks of varying types and ages (Nechoroschew, 1966, 14; Khain, 1994, 1). The study site of Berel' is located on widely distributed Palaeozoic rocks.

Both the East European or Russian Plain and the Ukrainian shield comprise an ancient crystalline basement. Sedimentary rocks of various thicknesses cover most parts of this crystalline basement, which consists of Precambrian granite and gneiss. These loess deposits originated in the Quaternary and are up to 100 metres thick (Dolukhanov, 2009, 9–10). A map of loess distribution (Fig. 2.16) shows that most of the study area is covered by loess layers of more than 5 metres, interrupted by river valleys without loess. While podsol is frequent in the more humid regions of the forest-steppes, chernozem is predominant in arid steppe areas. Chernozem consists of up to 90 % loess plus a small percentage of humus (Dolukhanov, 2009, 13–14) that developed under climatic changes, i.e. an increase in humidity, at the end of the Neolithic (Виноградов/Мамедов, 1975, 234–255; Parzinger, 1998, 459). All the study sites in the North Pontic region with the exception of Vinogradnoe, in southern Russia and the Middle Volga region are located in areas dominated by chernozem soil (Dolukhanov, 2009, 15 fig. 5). Chestnut coloured soils occur in the south of the steppes (Berg, 1959, 1; Kremenetski, 2003, 12), for example in Vinogradnoe. Loess is missing at the Lower and Middle Volga and in the study area of Bulgaria, where loess derivatives are distributed patchily at the study site Smyadovo. All the Bulgarian sites under investigation are located on brown soils, which are predominant in Bulgaria (Dolukhanov, 2009, 15 fig. 5). The study area in Hungary is dominated by alluvial deposits and sandy loess as well as, to a smaller extent, Aeolian sands.

Oxygen isotope ratios, and to a lesser extent also nitrogen and carbon isotope ratios, mainly reflect climatic conditions. It seems appropriate, therefore, to summarise the climate conditions of the steppes briefly here. The climate of the West Eurasian steppes is and was generally continental and characterised by cold winters, hot summers and low humidity (Dolukhanov, 2009, 12). To the east, within the steppe belt, summer temperatures increase and humidity decreases even further (Borisov, 1965, 130–131). Annual precipitation in the North Pontic region is approximately 400 mm with a decreasing

Table 2.5 | Altitude, air temperature, annual precipitation and $\delta^{18}O$ mean values recorded at GNIP stations in the study area [data from the Global Network of Isotopes in Precipitation database (IAEA/WMO 2006)].

GNIP station	country	altitude (m)	air temperature min (°C)	max (°C)	mean (°C)	precipitation (mm)	$\delta^{18}O$ (‰) weighted mean	$\delta^{18}O$ (‰) mean
Budapest	**Hungary**	139			10.6	487		
Bălţi	**Moldova**	231			7.8	344		
Chisinau	**Moldova**	125			11.7	472		
Odessa	**Ukraine**	64	–9.8	34.4	9.4	350	–9.00	–9.07
Kharkov	**Ukraine**	148			7.4	517		
Rostov	**Russia**	77			8.7	506	–8.56	–8.10
Saratov	**Russia**	166			6.8	462	–11.78	–10.94
Astrakhan	**Russia**	–18			10.6	221	–7.51	–7.87

gradient from west to east and north to south (cf. Rozanski et al., 1993, 5 fig. 4). Only few GNIP (Global Network of Isotopes in Precipiation) stations are located in the study area or in the vicinity. Table 2.5 shows the temperature, precipitation and $\delta^{18}O$ mean values provided by the GNIP stations in the study area and its immediate surroundings. Annual mean $\delta^{18}O$ values are collected from four of the GNIP stations. According to longitude and latitude, the most depleted ratios derive from the northernmost site Saratov, while the least depleted $\delta^{18}O$ is measured at Astrakhan, where almost semi-desert-like conditions occur.

Palaeoclimatic studies in Western Eurasia for the period under consideration are mainly published in Russian; therefore the following remarks are essentially based on the works of Kremenetski (1997; 2003), Gerasimenko and Pashkevich (Gerasimenko, 1997; Pashkevich/Gerasimenko, 2009), Klimenko and colleagues (2001) as well as secondary literature. Kremenetski's observations are based on pollen profiles in peats and bogs, and the palaeoclimatic reconstructions for the Western European part of Russia by Klimenko and colleagues are based on palynological data from peats. Gerasimenko, Pashkevich and Demkin, on the other hand, base their research on soil samples at archaeological sites.

In general, the climate of the steppes in prehistoric times underwent several climatic oscillations, sometimes connected to dramatic climate changes (Shishlina et al., 2012, 178 citing Демкин et al., 2002). The 5th millennium BC started with climate conditions that were warmer and more humid than today (Kremenetski, 2003, 13–14). The Eneolithic period, over vast areas of the East European Plain, did not exhibit continental conditions but was instead characterised by mild winters and slightly higher mean annual temperatures than today (Pashkevich/Gerasimenko, 2009, 46). This period of cool and humid climate conditions was still in evidence at the end of the 4th millennium, paralleling the beginning of the Early Bronze Age Yamnaya culture (Klimenko et al., 2001, 190). By the beginning of the 3rd millennium BC, however, the climate had started to become more arid with accompanying changes in vegetation, a trend which intensifies over the course of the millennium (Klimenko et al., 2001, 191; Kremenetski, 2003, 12 fig. 2.1; Pashkevich/Gerasimenko, 2009, 49–50). Although several climatic oscillations occurred after 2800 BC (Kremenetski, 2003, 14), the general trend of progressive aridisation is suggested to have continued until the end of the 3rd or the early 2nd millennium BC (Anthony, 2009, 48). In the later first half of the 2nd millennium BC a cooler and more humid climate sets in; this lasts up to the beginning of the 1st millennium BC (Bokovenko,

2004, 31). The 1st millennium, the Scythian period, was marked by episodes of cooling (Klimenko et al., 2001, 191).

The prehistoric climatic oscillations had an effect on vegetation, which changed as it adapted to the varying conditions. In general, the vegetation zones of Western Eurasia can be roughly divided into forest belt, forest-steppe belt, steppe belt and a zone of semi-desert. The prehistoric distribution of forest-steppe and steppe zones is similar to today (Parzinger, 1998, 458). Grasses dominate the steppe environment; the northern steppes include meadows, where grasses are mixed with legumes and flowers, whereas the drier southern steppes are predominantly made up of narrow-leaved feather grasses (Dolukhanov, 2009, 13). Before 2800 BC, the North Pontic steppe terraces of the rivers Don, Severskii Donets and Dnieper were covered by mixed woodlands of birch and pine (Kremenetski, 2003, 12). The ecological conditions of the Yamnaya period are usually described as being rich grasslands formed during a climatic optimum (Kristiansen/Larsson, 2005, 172). At the end of the 3rd millennium BC, the climate became generally drier leading to a change of vegetation cover from mixed meadows to grass steppes (Melyukova, 1995, 27; Kremenetski, 2003, 11; Bunjatjan/Nikolova, 2006, 1) with a decline of woodlands in areas like the lower Don River (Kremenetski, 2003, 13; Kaiser, 2003, 19). The steppe belt expanded to the north and wormwood-bunchgrass steppe became the dominant vegetation (Gerasimenko, 1997, 371). The south of the steppes was virtually totally treeless, with trees only surviving in the ravines and river valleys (Kremenetski, 2003, 12; Pashkevich/Gerasimenko, 2009, 50). After approximately 1000 years of arid climate conditions, between 1500 calBC to the beginning of the 1st millennium BC, precipitation increased and temperatures decreased and the woodlands expanded again as a consequence (Bokovenko, 2004, 31). Later, from around 600 BC onwards, a similar vegetation cover as exists today is recorded for the North Pontic region (Kremenetski, 2003, 14–15).

In the northwest Caspian steppe region Shishlina and colleagues (2012) were able to correlate changing climatic conditions with vegetation and consequent economic changes. While the modern climate of the northwest Caspian region is characterized by very hot summers and severe winters, the period between 4800 and 3200 BC was characterised by a climatic optimum with lower summer temperatures and higher annual precipitation (Borisov, 1965, 130–131). During the Eneolithic, at the end of the 5th and the beginning of the 4th millennia BC, climatic conditions in the Caspian steppes were favourable for a mixture of grass and steppe landscape, with a predominance of C_3 plants, crossed by rivers and freshwater lakes with mixed forests in ravines and river valleys (Shishlina et al., 2009, 483 table 1). The following period between 3200 and 600 BC was characterised by several climatic oscillations. The Early Bronze Age in the first half of the 3rd millennium BC had a warm and more humid climate, associated with mixed grass steppes (Kremenetski, 1997, 43; Shishlina et al., 2009, 483 table 1). The vegetation cover of the dry steppe consisted of wormwood, leguminous and grass plants, turf steppe gramineous plants, goosefoot, lily and dicotyledonous mixed grasses. Similarly, the watershed steppe was covered by flora of mixed grasses steppes and mixed grasses and gramineous steppes types (Shishlina, 2001, 125; 2004, 93–94). As the 3rd millennium progressed, the climate became drier, with a decrease in precipitation and more extreme temperatures (Shishlina et al., 2012, 187 fig. 5 based on Демкин et al., 2002). The increased aridity led to the development of vegetation characteristic of semi-deserts and dry steppe with small forests in ravines also less frequent (Kremenetski, 1997, 32–33, 43; Shishlina, 2004, 94–95; Shishlina et al., 2009, 483 table 1; Shishlina et al., 2012, 183). Indirect evidence for climate aridisation is provided by the presence of fish bone of carp, sturgeon and pike-perch in Catacomb culture graves (Shishlina, 2004, 94 citing Шилов, 1975) and a trend of increasing $\delta^{15}N$ values in herbivores and humans over time (Shishlina et al., 2012).

Further to the East, in the Middle Volga region, the climate is a moderate continental one, characterised by long and cold winters and shorter hot and dry summers. After 4800 BC, forest cover increased in this region and only declined after 3200 BC with the increase in the steppe environment corresponding to the arid phase between 3200 and 1800 BC recorded in the Northern Pontic region and Southern Russia (Kremenetski, 2003, 18).

3 Sample sites and Material

3.1 Introduction

Chapter 2 was dedicated to setting out the archaeological and methodological background, and chapter 3 will introduce the sites and materials selected for $^{87}Sr/^{86}Sr$, $\delta^{18}O$, $\delta^{15}N$ and $\delta^{13}C$ analyses. The archaeological and anthropological background of each sample site will be summarized below, based on information given in the appendix catalogue (Appendix A), which consists of publications, unpublished excavation reports and personal communications. Information on the local geology is mainly drawn from the geological map IGME 5000 (Asch 2005). The selection of sample sites was guided by the overall objective to address different regions over different periods of time (Fig. 3.1).[1] 14 skeletons were selected from four sites of the Eneolithic period. 76 skeletons were selected from 21 sites of the Early Bronze Age period, and 24 skeletons were selected from seven sites of the Middle Bronze Age. 28 skeletons were selected from six sites dating to the Iron Age. Sample sites are introduced below, arranged primarily in sections according to their time period, then location and are listed alphabetically within each section.

Fig. 3.1 | | Sites sampled: 1 Smyadovo, 2 Benkovski, 3 Ovchartsi, 4 Boyanovo, 6 Balmazújváros, 7 Debrecen, 8 Püspökladány, 9 Sárrétudvari, 10 Dévaványa, 11 Kétegyháza, 12 Kirovograd, 13 Peshtchanka, 14 Vinogradnoe, 15 Shakhta Stepnaya, 16 Nevskoe, 17 Olennii, 18 Sukhaya Termista, 19 Politotdel'skoe, 20 Nikolaevka, 21 Podlesnyi, 22 Kalinovka (all Eneolithic and Bronze Age; green symbols), 23 Alexandropol', 24 Babina Mogila, 25 Drana Kokhta, 26 Ordzhonikidze, 27 Zolotaya Balka, 28 Berel' (all Iron Age; yellow symbols).[2]

1 The author was not involved in the sample site and sample individual selection process.

2 No. 5, the tell settlement site of Uivar, dates to the late Neolithic and early Copper Age and was evaluated in another context.

3.2 Eneolithic and Bronze Age[3]

3.2.1 Carpathian-Balkan region

3.2.1.1 Bulgaria

26 samples were selected for isotopic analysis from four sites in the territory of modern Bulgaria. The Eneolithic and Early Bronze Age flat grave cemetery near Smyadovo, in the district of Shumen, is located in northeastern Bulgaria on the southeastern edge of the Danubian Plain at the northern foot of the eastern Balkan Mountains. The burial mounds near Benkovski, in the district of Nova Zagora, and Ovchartsi, in the district of Radnevo, are both in Central Bulgaria, while Boyanovo, in the district of Yambol, is located in the vicinity of the river Tundzha in southwest Bulgaria.

The sites differ in their geology (Fig. 3.2), though the three sites in the southern part of Bulgaria have broadly comparable underlying geology. Benkovski is located on a plain of Tertiary geology overlain by Quaternary alluvial sediments. Within a radius of 20 km, the bedrock includes older Palaeozoic plutonites, Permian to Jurassic metamorphic and late Cretaceous rocks to the east, and Triassic, Jurassic and Cretaceous rocks to the north. Boyanovo also lies on Quaternary alluvial sediments of floodplains and river terraces. It is located in an area of metamorphic rocks of Permian to Jurassic age, with some areas of Pliocene age with Cretaceous rocks and Mesozoic plutonites less than 10 km distant. The site near Ovchartsi sits on Cenozoic sediments such as clays and sands, but the geology within a 10 km radius of the site is rather varied, with Mesozoic plutonites and Permian to Jurassic metamorphic rocks. There are also outcrops of Palaeozoic, partly metamorphic, rocks within 50 km. Smyadovo is very different, located in a hilly region of Cretaceous deposits with Jurassic rocks occurring less than 10 km away. Cenozoic sediments and Triassic-Jurassic outcrops can be found within a radius of 20 km. There are also significant differences in climate and ecology between Smyadovo and the other sample sites due to its proximity to the mountains, its elevation and its latitude.

Benkovski
The site comprises a group of five burial mounds, two of which were excavated in 2008 and 2009 by St. Alexandrov and P. Karailiev. Kurgan 1 has a diameter of 20 m and a preserved height of 0.4 m and contained three burials dating to the Early Bronze Age, while kurgan 2 is slightly smaller with a diameter of 16 m and a height of 0.3 m and contained nine Early Bronze Age graves. For this study, samples were taken from two burials in kurgan 1 and seven burials in kurgan 2. The majority of the pit graves were rectangular in shape and contained single burials of skeletons in supine positions with flexed legs. The individuals were mainly oriented W–E and SW–NE. Where sex and age could be identified, the graves contained males or probably males. Age groups varied and can be categorised as one infant, two juveniles, one young and three old adults. The graves were poorly furnished with ochre spread in graves 2.4 and 2.7 and a single ceramic fragment in grave 2.3.

One tooth was analysed from each of the individuals with the exception of graves 2.2 and 2.3, from each of which two teeth were sampled. In total eight first, two second and one third molar were analysed for their strontium and oxygen isotope ratios and for strontium isotope concentrations. One sediment

3 Sites dating to the Eneolithic and to the Bronze Age have been summarized in the same category, because all sites dating to the Eneolithic also contained skeletons from the Bronze Age.

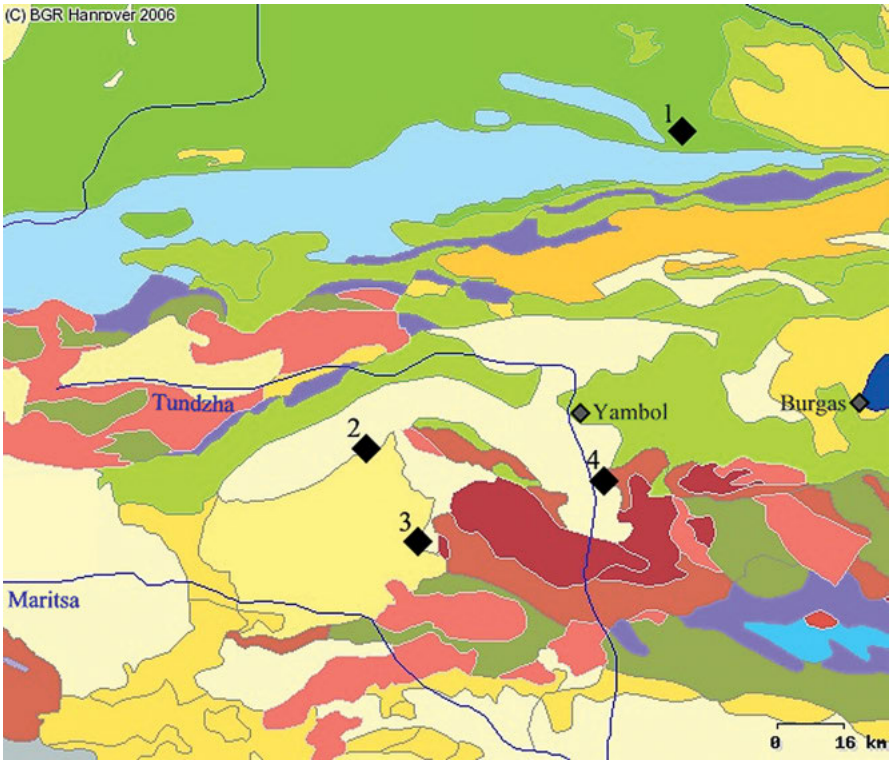


Fig. 3.2 | Geological map (based on Asch, 2005; scale: 1.016.969) including sample sites in Bulgaria: 1 Smyadovo, 2 Benkovski, 3 Boyanovo, 4 Ovchartsi.

Geological Age:
Cenozoic: Pliocene-Palaeocene (yellow),
Mesozoic: Cretaceous (green), Jurassic (blue), Triassic (purple),
Palaeozoic: Permian (auburn), Carboniferous (grey), Palaeozoic unspecified (olive)

Magmatic rocks: Cenozoic-Palaeozoic plutonite (red)

sample and one plant sample from the immediate area, a pig's tooth from pit 15 of an excavation in Sabrono, 3 km north of Benkovski, and four dentine samples were analysed to establish the range of locally available strontium.

Boyanovo

Excavations were conducted at Boyanovo by D. Agre in 2007 and 2008. The Lonzynskaya kurgan belongs to a group of six mounds that overlook the plain. The kurgan measures more than 30 m in diameter and was approximately 5.5 m high at the time of excavation. It contained 22 graves, of which nine can be dated to the Early Bronze Age, twelve to the Middle Bronze Age and one to the Iron Age. Five of the Early Bronze Age burials are ascribed to the Yamnaya culture. Samples were taken from the Lozynskaya Tumulus graves 5, 6 and 14 dating to the Early Bronze Age and grave 4 dating to the Middle Bronze Age. The shape of the grave pits, all oriented W–E or SW–NE, ranged from round to ellipsoid and oval. Most of the skeletons were placed in a supine position with crouched legs. Apart from the double burial in grave 14 all graves contained single burials. The main features of the graves were their wooden coverings, organic substrates, ochre pieces and one silver hair ring found in grave 14. The Middle Bronze Age burial

4 contained a ceramic vessel. No anthropological information is available for the moment, but skeleton 1 in grave 14 is considered to be male and skeleton 2 in grave 14 may be female.

One tooth was sampled from each individual, two samples were analysed from the individuals in graves 4 and 14, skeleton 1. In each case, strontium and oxygen isotope ratios were analysed. The following were analysed to define the local strontium signature: one sediment sample, a couple of land snails, a pig tooth from an excavation in Elhovo and three dentine samples.

Ovchartsi

The 'Kurgan in the Vineyards', a single burial mound of 1 m extant height and 10 m in diameter, is located on a plateau in a valley. Seven burials belonging to the Yamnaya cultural groups were excavated in a rescue excavation. 'The Big Tumulus' is another single burial mound with a diameter of approximately 45 m and unknown height that is situated on a hill. Here, 15 burials belong to the Yamnaya cultural groups. Excavations were conducted in 1986 by H. Buyukliev and P. Kalchev and in 2002 by I. Panayotov and St. Alexandrov. Five human individuals were selected for isotopic analysis: grave 3 of the 'Kurgan in the Vineyards' and graves 1, 2 (skull south), 9 and 15 (skull west) of 'The Big Tumulus'. Most individuals were buried in rectangular pits with varied orientations. The single burial in grave 3 is the primary burial of the 'Kurgan in the Vineyards'. Two single and two double burials were sampled from 'The Big Tumulus'. Most individuals were male and were laid on their back with their legs crouched and varied in age between juvenile and mature. Artefacts associated with the burials included spread of ochre and ceramic vessels and fragments. Two graves were comparatively well-equipped, one containing bones and charcoal ('The Big Tumulus' grave 9), the other a stone tool, two animal bones and charcoal ('Kurgan in the Vineyards' grave 3) in addition to the artefacts mentioned above.

The first permanent molars were sampled from all burials and analysed for both strontium and oxygen isotope ratios. The third molars were also sampled from graves 9 and 15 in 'The Big Tumulus'. The following were sampled to establish the biologically available $^{87}Sr/^{86}Sr$ range for the area around Ovchartsi: one sediment sample, one plant sample and three dentine samples.

Smyadovo

The flat grave cemetery of Smyadovo is situated on a slope and contains 23 graves, of which 18 belong to the Eneolithic and five to the Early Bronze Age. Excavations conducted by St. Chokhadzhiev and S. Venelinova took place in 2007. Seven of the eight individuals selected for sampling were buried in grave pits dating to the Eneolithic. In most cases the shape of the burial pits was not visible. The predominant orientation of the skeletons, which were buried on the left side in a crouched position, was E–W. All burials were single and ages varied between infant and adult. Four males and two females as well as two skeletons of unknown sex were sampled. Burial objects included ceramics, ochre pieces, spondylus, a copper fragment and a bone awl. Grave 6 was exceptionally well-equipped, with four ceramic vessels, one stone axe, one piece of copper, spondylus and ochre pieces. The archaeological evidence, the presence of an ochre piece and spread, ceramics, a bone artefact, place the individual in grave 26 in the Early Bronze Age.

Enamel samples for strontium and oxygen isotope analysis were taken from graves 6, 10, 11, 13, 15, 16, 22 and 26. First molars were chosen for sampling, except for grave 26, where a third molar was used. Third molars were also sampled from graves 6 and 22, in addition to the first molars. The local $^{87}Sr/^{86}Sr$ signature was established from one sediment sample, one plant, one faunal and three dentine samples.

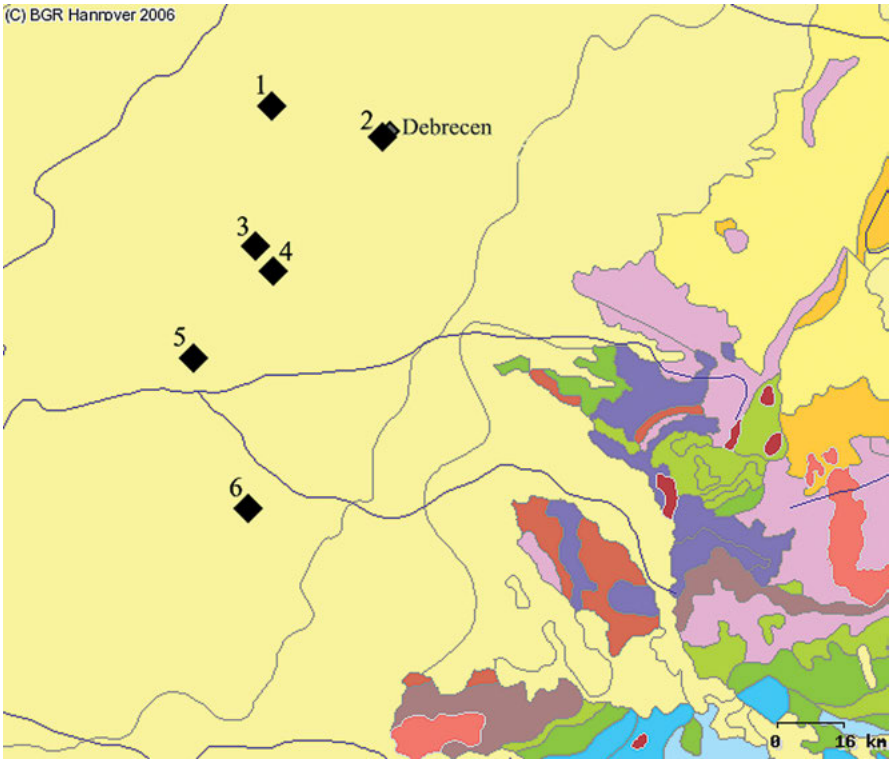


Fig. 3.3 | Geological map (based on Asch, 2005, scale: 1.016.969) including sample sites on the eastern Hungarian Plain: 1 Balmazújváros, 2 Debrecen, 3 Püspökladány, 4 Sárrétudvari, 5 Dévaványa, 6 Kétegyháza.

Geological Age:
Cenozoic: Miocene-Palaeocene (yellow)
Mesozoic: Cretaceous (green), Jurassic (blue), Triassic (purple)
Palaeozoic: Permian (auburn), Variscan (claret)
Precambrian: Proterozoic (dark pink)

Magmatic rocks: Mesozoic plutonite (dark red), Palaeozoic plutonite (light red)

3.2.1.2 Hungary

One of the areas of the Yamnaya burials west of their core Yamnaya distribution area is the region east of the river Tisza on the Great Hungarian Plain (cf. Heyd, 2011). 19 samples from nine Early Bronze Age burial mounds were selected for isotopic analysis.

This sampling region is relatively homogeneous geologically (Fig. 3.3), climatically and ecologically. The eastern Hungarian Plain is predominantly composed of Cenozoic sediments and characterised by steppe-like conditions. The sites are located less than 100 km from the foothills of the Apuseni Mountains, part of the Carpathian Mountain range which lie to the southeast. This mountainous region is composed of bedrocks of various periods ranging from the Precambrian to the Mesozoic.

Excavations of the study area were concentrated at the beginning of the 20th century and in the 1960s. The majority of the sample sites are located in Hajdú-Bihar County and belong to the group of

burial mounds near Debrecen that were excavated by L. Zoltai in the years between 1907 and 1927. This is the burial mound Debrecen-Dunahalom and the kurgans Debrecen-Basahalom and Sárrétudvari-Balázshalom. The latter two mounds had impressive dimensions of 60 m in diameter and 6.5 to 8 m in height. Two of the sampled burial mounds, Balmazújváros-Árkusmajor-Kettőshalom and Balmazújváros-Árkusmajor-Kettőshalom, were excavated in the 1960s by Gy. Gazdapusztai and I. M. Nepper respectively. Two sites selected for analysis in Békés County were Dévaványa-Barcéhalom and Dévaványa-Csordajárás. Dévaványa-Barcéhalom, with a height of 2 m, was erected in several building stages and covered two burials. Excavations were restricted to a small area of the site, and therefore the central burial was left untouched. In the course of rescue excavations, three burials were discovered in the central part of the base of the burial mound Dévaványa-Csordajárás. The identical nature of the burial rite has led to the assumption that the burials were contemporaneous and predate the erection of the mound.

The sampled individuals from these burial mounds belong to the Yamnaya burial tradition of the Early Bronze Age. Skeletons were mainly placed as single burials in rectangular pits, which were oriented W–E and covered by mounds. In most cases the deceased were adult males, laid in supine positions with flexed legs, although exceptions occur. Burial objects, if not absent, contained elements like pieces or spreads of red ochre, ceramics, organic mats covering the pit floor and plastered elements. Ceramics and animal bones also occurred in the grave fill.

The following teeth were selected for strontium and oxygen isotope analysis: One first molar was chosen from grave 3 in Dévaványa-Csordajárás, second permanent molars were selected from Balmazújváros-Árkusmajor-Kettőshalom, grave 3 in Dévaványa-Csordajárás, Püspökladány-Kincsesdomb and Sárrétudvari-Balázshalom and third molars from Debrecen-Basahalom and Dévaványa-Barcéhalom. Two samples, one second and one third molar were selected for analysis from Debrecen-Dunahalom. Dentine samples served as references and were taken from the burials in the kurgans Balmazújváros-Árkusmajor-Kettőshalom, Dévaványa-Barcéhalom and Dévaványa-Csordajárás (grave 3).

Two of the burial mounds on the Hungarian Plain provided several samples and are briefly introduced below:

Kétegyháza-Kétegyházi tanyák

The site, located in Békés County, consists of a kurgan field as well as settlement remains from different time periods from the Neolithic to the Late Middle Ages. Excavations in the kurgan field were carried out between 1966 and 1968 under the supervision of Gy. Gazdapusztai. Samples were taken from kurgan 3, which lies in line with two other mounds on a low, natural rise. It had an estimated height of 7.08 m and was possibly built in three phases. The sampled grave (grave 7) was covered by the first building phase of the kurgan mound, followed by four Yamnaya and three Sarmatian graves. Kurgans 5a (grave 1) and kurgan 6 (graves 1 and 3), both heavily eroded, were part of another line of burial mounds. The sampled individuals date to the Early Bronze Age and were mainly the primary burials of the kurgans. They were buried in supine positions with crouched legs as single burials oriented W–E in oval or rectangular pits and comprised two adult males, one adult female and one juvenile. The graves were characterised by organic substrates, with red and yellow ochre staining. They contained no or poor grave goods with the exception of grave 7 in kurgan 3.

Second molars were sampled, except in the case of grave 7 in kurgan 3, where a first molar was sampled. A dog's tooth, an astragal of a sheep and two dentine samples from the same excavation were analysed as reference material.

Sárrétudvari-Őrhalom
The burial mound Őrhalom near the village Sárrétudvari is situated in Hajdú-Bihar County. It is a single kurgan, excavated in the 1980s and 1990s by I. M. Nepper and J. Dani. Seven graves dating to the Late Eneolithic and Early Bronze Age were identified in addition to burials dating to the Hungarian Conquest Period. All Eneolithic (grave 12) and Early Bronze Age burials (graves 4, 7, 7a, 8, 9, 10, 11) were selected for isotopic analysis. Burial pits were of rectangular, oval, irregular or unknown shape. The burials were mainly oriented NW–SE and NE–SW. All graves contained single burials except grave 7/7a. The presence of burial goods varied from none (graves 12, maybe 8) to abundant (graves 4, 7/7a), with elite burial objects such as *Lockenringe*, ceramic vessels, a copper axe and dagger and a piece of ochre. The remains of organic mats were discovered in most graves and skeletons were found placed on their side. The skeleton in the primary grave 12 was identified as a juvenile female, the rest were adult and mature males, a child (grave 7a) and a juvenile (grave 8).

Enamel from the second premolar (graves 11, 12) and the first (graves 4, 7a, 8, 12), second (7, 7a, 8, 10) and third (graves 4, 9) molars were taken for analysis. Four dentine samples were analysed to establish the local signature, as well as one sediment sample, one plant sample, a cattle tooth and two sheep bones.

3.2.2 North Pontic region

Two sample regions can be distinguished in the North Pontic due to their similar geological and ecological settings.

3.2.2.1 Central Ukraine

Four sites in Central Ukraine, the burial mounds near Kirovograd, Peshtchanka, Shakhta Stepnaya and Vinogradnoe, were selected for isotopic analysis, providing 36 samples from humans dating from the Eneolithic to the Middle Bronze Age Catacomb culture. Though they are widely dispersed, the sites are all located within the North Pontic steppe zone in the vicinity of rivers. The geology is a mixture of Proterozoic and Archaean geology and Cenozoic sediments (Fig. 3.4). The geological bedrock near Kirovograd is made up of Palaeocene sediments and Proterozoic magmatic plutonites. The kurgans near Peshtchanka are situated near the mouth of a tributary of the Samara River into the Dnieper, on a plain made up of Cenozoic sediments, but with Proterozoic plutonites less than 10 km away. The site Shakhta Stepnaya is located near an oxbow lake of the Samara River on a plain of homogeneous Cenozoic sediments. Carboniferous and Archaean bedrock and Proterozoic plutonites occur approximately 50 km away. The burial mounds of Vinogradnoe are located on the terraces of the valley of the Molochnaya River, composed of Miocene sediments, while the surrounding plain comprises Pliocene sediments.

Kirovograd
The kurgan Sugokleya, located at the western periphery of the city of Kirovograd in the region and district of the same name, has a diameter of approximately 50 m and a preserved height of 5.6 m. Excavations took place in 2004 under the supervision of Y. V. Boltrik. Three Early Bronze Age phases can be identified. The sampled burials belong to the Yamnaya and Catacomb cultural groups. The Yamnaya

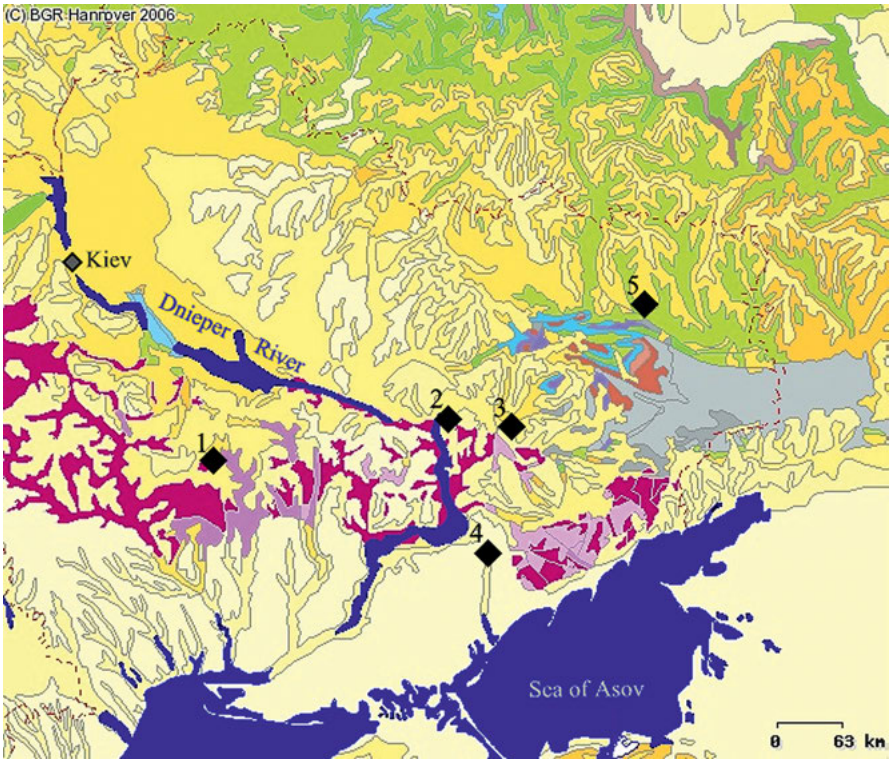


Fig. 3.4 | Geological map (based on Asch, 2005; scale: 4.067.875) including sample sites in the North Pontic: 1 Kirovograd, 2 Peshtchanka, 3 Shakhta Stepnaya, 4 Vinogradnoe, 5 Nevskoe.

Geological Age:
Cenozoic: Pliocene-Palaeocene (yellow)
Mesozoic: Cretaceous (green), Jurassic (blue), Triassic (purple)
Palaeozoic: Permian (auburn), Carboniferous (grey), Devonian (claret)
Precambrian: Proterozoic (dark pink), Archaean (light pink)

Magmatic rocks: Proterozoic plutonite (reddish pink)

burials were found in rectangular pits with partly rounded corners, some of which had additional platforms. The burials, mainly single ones, had various orientations. The graves contained postholes and the remains of wooden constructions. Ochre staining, ochre colouring of skeletal parts and pieces of ochre were discovered in all the Yamnaya graves. The number and type of burial objects varied greatly and included anything from ochre, animal bones, ceramic vessels, a wooden mace, a flint flake in the backfill to disc wheels, a decorated ceramic vessel, wagon parts, fragments of a wooden cup, a horse tooth and shells. Most Yamnaya skeletons, primarily male adults, were buried in a supine position with crouched legs. The authenticity of the wide span of ^{14}C measurements from 4340 ± 80 BP (grave 24) to 3470 ± 90 BP (grave 10) is discussed in Nikolova and Kaiser (2009). Grave 13 was the only grave sampled that dated to the Developed Catacomb cultural groups and contained the single burial of an adult male, which was buried in a SW–NE oriented catacomb grave including a *dromos*. Burial objects included a decorated ceramic vessel, a stone axe and a piece of ochre.

For strontium and oxygen isotope analysis, two teeth were sampled from each individual: the first molars were sampled from burials 5, 10 (child), 13 and 24; second molars were taken from burials 5, 10

child and adult, 13, 20, 24, and third molars were analysed of burials 10 (adult) and 20. A wide range of references included two sediment samples, one plant, one horse tooth, snails, three dentine and two bone samples.

Peshtchanka

A group of burial mounds was discovered near the village of Peshtchanka in the region of Novomoskovsk in the district of Dniepropetrovsk. Kurgan 1 of kurgan group 2 contained five Eneolithic, six Yamnaya and four Catacomb culture graves. The results of the excavations, which took place in 2007 under the supervision of D. Teslenko, are hitherto unpublished. Four of the sampled graves, burials 6, 7, 14 and 15, belong to the Eneolithic. The grave pits are oval or rectangular and mainly oriented NE–SW. Most burials are single ones and belong to the primary stage of the burial mound. Skeleton positions, sex and age varied. Graves were unfurnished or included traces of organic mats and ochre staining, and objects like copper rolls, a flint object and one piece of ochre. The two Yamnaya graves 10 and 11 contained single burials. The rectangular pits with platforms had various orientations. Both skeletons were in a crouched position on their right side. The graves were covered by wooden material and contained organic mats. Grave 10 also contained one ceramic vessel, a flint arrowhead, a piece of ochre and one raptor claw. Grave 12, belonging to the Catacomb culture, contained a single burial in a rectangular catacomb with SE–NW orientation. The skeleton was laid on an organic mat and the skull was covered by a plaster mask.

All skeletons were analysed twice for strontium and oxygen isotope ratios. The first and second molars from graves 6, 10, 11, 12, 14 and 15 as well as a second and third molar of burial 7 were taken for analysis. Two sediment samples, one plant sample, one cattle tooth, two dentine and two bone samples were analysed to establish the local $^{87}Sr/^{86}Sr$ range.

Shakhta Stepnaya

This site, with four burial mounds, is situated in the region of Petropavlovsk in the district of Dniepropetrovsk. The four kurgans are arranged in a line and three of them were excavated in 2007 by V. A. Romashko. The kurgans contained burials from the Eneolithic to the Medieval period. Two of the sampled graves belong to the Yamnaya culture. The rectangular burial pits with wooden covers and platforms were oriented SE–NW and E–W and contained single burials. The skeletons were placed in crouched positions on their side. Grave 2.7 had no grave goods, but grave 4.11 contained a flint blade and an object made of leather beside an ochre spread. Two individuals dating to the Developed Catacomb culture were also sampled. The graves are irregular in shape and orientation, as are the positions of the female skeletons. The graves are characterised by a wooden cover, ochre spread, ceramic vessels and objects made of wood or leather.

The first molars from burials 2.4, 2.7 and 4.10, third molars of burials 2.7 and 4.10 and a second and third molar of burial 4.11 were taken for analysis. Dentine, bone, one sediment sample, one plant sample and one shell were sampled to establish the local $^{87}Sr/^{86}Sr$ range.

Vinogradnoe

The village of Vinogradnoe is located in the Tokmak region in the district of Zaporozhe. A group of several dozen burial mounds are aligned along the terraces of the valley of the Molochnaya River. Samples were taken from burial mounds 3 and 24, both excavated by Y. Ya. Rassamakin. Kurgan 3 had a height of 8 m and a diameter of approximately 100 m. Several kurgan embankments cover 49 graves, dating to

the Eneolithic and the Bronze Age. Burial mound 24 was much smaller in size with diameters of 54 m to 62 m and a height of 5 m. 31 burials were covered beneath several embankments, belonging to the Eneolithic, the Bronze and the Early Iron Age. 16 samples were selected dating to the Eneolithic, the Yamnaya, the early and the developed stage of the Catacomb culture. The two Eneolithic burials had oval grave pits, oriented E–W, and contained primary burials of single male adult skeletons. Differences in the grave goods and positions of the skeletons imply that they belong to different cultures. The four burials belonging to the Yamnaya culture contained male adult skeletons, placed crouched on the side in rectangular or oval pits. Grave contents varied from no burial objects to a large number including wooden covers, organic mats, wooden wheels, ceramic vessels, bronze, copper and bone objects and ochre spread. The six Early Catacomb culture graves mainly contained male adults, which were placed crouched on the right side in rectangular pits with various orientations. Although graves were primarily unfurnished, the few burial objects present included silver, copper, flint and stone objects and wooden wheels. The four graves that were ascribed to the Developed Catacomb culture contained skeletons in oval pits of various positions and orientations. Some graves had no grave goods while others had organic mats, ochre spreads and wooden objects.

The first and second molars were sampled from the individuals in graves 3.36, 24.8 (individuals 1 and 2), 24.17 (individual 1) and 24.32. The first and third molar was sampled from 24.22. Second and third molars were analysed from 3.25, 24.15 (individual 2), and 24.26. Only second molars were sampled from grave 3.15, and only third molars were analysed from graves 24.15 (individual 1), 24.19, 24.30, 24.31, 24.34 (individuals 1 and 2). Dentine and bone samples were taken to establish the local $^{87}Sr/^{86}Sr$ range, in addition to three sediment and one plant samples, two rodent teeth, one shell and two teeth from a dog or wolf.

3.2.2.2 East Ukraine

Nevskoe

The site is located in the Kremenskyi region in the district of Lugansk in Eastern Ukraine. In contrast to the sites in Central Ukraine, the underlying geology is made up of a mixture of Cretaceous bedrock and Cenozoic sediments, with Triassic and Palaeozoic geology less than 50 km distant (Fig. 3.4).

The burial mounds were excavated in 1998. All five graves that were sampled date to the Kharkov-Voronezh regional variant of the late Catacomb culture with one ^{14}C date of 3640 ± 70 BP given for grave 10 in kurgan 2 (Klochko/Sanzharov, 2003, 209 table 1). The graves consist of rectangular or oval entrances to chambers that are mainly oriented S–N. The graves primarily contained single burials in crouched positions lying on the right side. All individuals were adults. An ochre spread was recorded for most graves, and grave covers for some. Grave goods included ceramic vessels, wooden cups, a piece of ochre, animal bones and charcoal. Two ochre foot prints were discovered in grave 9 of kurgan 5.

First molars were sampled from burials 3.3 and 5.9, a second molar from burial 4.2 and third molars from burials 2.10 and 4.3. The local $^{87}Sr/^{86}Sr$ signature was established from three dentine samples in the absence of other suitable reference materials.

3.2.3 Russia

3.2.3.1 Volga region

Three sites on the middle Volga and one site on the lower Volga were selected for analysis, providing 17 individuals for sampling. Three sites, the burial mounds near the villages Kalinovka, Nikolaevka and Podlesnyi are located in the district of Samara and have similar geological and ecological settings. They are sited in the vicinity of the river Samara and its tributary rivers. The underlying geology is made up of Pliocene sediments and Permian outcrops (Fig. 3.5), with Triassic and Cretaceous bedrock less than 50 km away. The fourth site, Politotdel'skoe, is located further south near the river Volga in the district of Volgograd. The site is positioned on an area of Cenozoic sediments along the river valley with 'islands' of Cretaceous and, less commonly, Permian and Jurassic outcrops occurring less than 20 km from the site.

The individuals selected for sampling are attributed to the Poltavka culture, the local manifestation of the Catacomb culture in the Volga region, and shares elements of the Yamnaya as well as the Catacomb culture. The majority of the sampled skeletons were buried as single burials in rectangular pits.

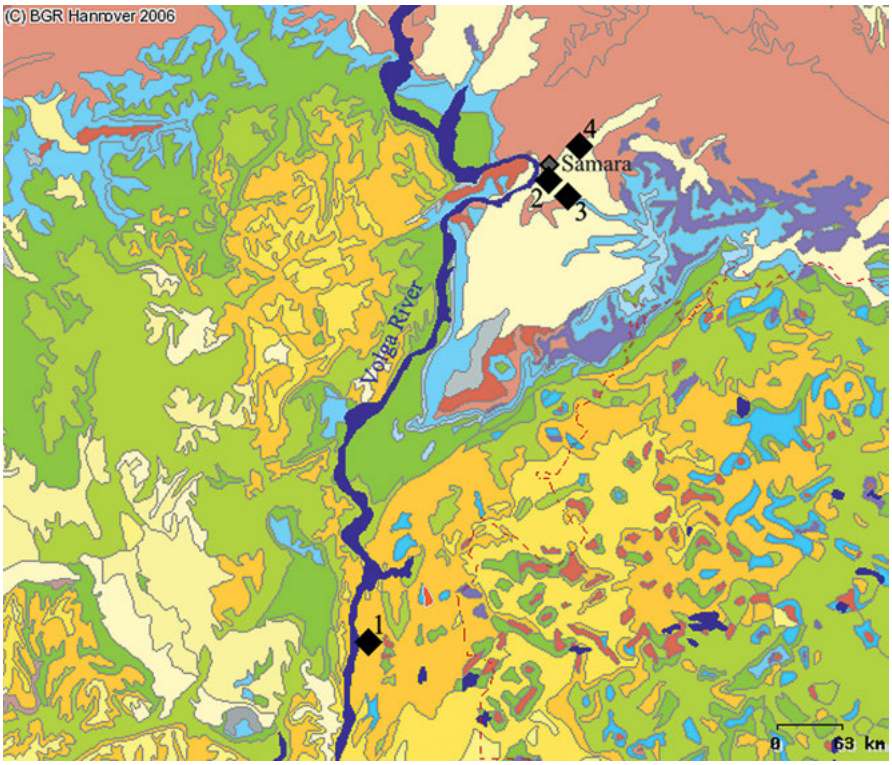


Fig. 3.5 | Geological map (based on Asch, 2005; scale 4.067.875) including sample sites in the Volga region: 1 Politotdel'skoe, 2 Nikolaevka, 3 Podlesnyi, 4 Kalinovka.

Geological Age:
Cenozoic: Quaternary-Palaeocene (yellow)
Mesozoic: Cretaceous (green), Jurassic (blue), Triassic (purple)
Palaeozoic: Permian (auburn), Carboniferous (grey), Devonian (claret)

The pits are often oriented E–W, but variations do occur. Most of the skeletons were placed in crouched positions on one side. Frequently, these were adult males, but there were also female skeletons and infants. Grave furnishing was generally poor, but if present, included wooden grave covers, organic mats and pillows, ochre pieces and spread, ceramics including 'coal pans', copper objects, grinding stones, shells, animal bones and charcoal.

Kalinovka I

In the vicinity of the village Kalinovka is a group of 11 burial mounds, five of which have been excavated. Excavations by D. A. Stashenko took place in 1998 and 2005. At the time of excavation, kurgan 1 had a preserved diameter of 24 m to 26 m and a height of 0.6 m. The mound covered seven burials, five of which are attributed to the Poltavka culture and two to the Sarmatian period.

Samples for strontium and oxygen isotope analyses were taken from the first molars from burials 3 and 4 and the third molar from burial 6. In addition, animal bones from graves 4 and 5 and dentine from graves 3 and 4 were sampled to establish a local signature.

Nikolaevka III

The kurgan group Nikolaevka III, located in the Volzhskii region, consists of six burial mounds that are oriented in a line on the 2nd terrace of the river Samara. Excavations took place in 1995 by V. A. Skarbovenko. Samples were taken from kurgans 1, 2, 3 and 5, which had similar preserved diameters of between 20 and 30 m, and heights of between 0.3 and 0.4 m. Kurgan 1 covered five Bronze Age burials and kurgan 3 four burials with entrance shafts. Kurgans 2 and 5 each contained one Bronze Age burial.

Only one tooth was analysed from most individuals for strontium and oxygen isotope ratios. These were first molars of burials 3.1.1, 3.1.2, 3.4 and 5.1 and second molars of burials 1.2, 1.3 and 2.1.1. Individual 2 from grave 2.1 was sampled twice (first and third molar). In the absence of further references, three dentine samples were analysed to establish the local signature.

Podlesnyi

The group of burial mounds near the village of Podlesnyi is situated in the Volzhskii region and consists of eight kurgans, arranged in a line. Two of these mounds, kurgans 3 and 5, were excavated in 1997 and 2000 by P. P. Barynkin. When it was excavated, kurgan 3 had a diameter of 24 m and a height of 0.2 m to 0.35 m and covered 7 burials.

The first molars of all three individuals were analysed, with a third molar from grave 6. In the absence of further reference material dentine samples from all three individuals were analysed to establish a local signature.

Politotdel'skoe

Politotdel'skoe is located in the Nikolaevskii region and consists of a group of four burial mounds, three of which are arranged in a line. Kurgans 2, 3 and 4 were excavated in 1989 by O. V. Kuzmina. Kurgan 2 measures 13 m in diameter and has a preserved height of 0.3 m. It covered seven Catacomb graves. No information is available on kurgan 4 except the fact that it covered more than 14 graves.

A first molar from burial 4.6 and two second molars from burials 2.2 and 2.3 were sampled. Two dentine samples of burials 2.2 and 2.3 were analysed to establish the local Sr range.

3.2.3.2 Kuban and Northwest Caspian Sea region

The two sites, Olennii and Sukhaya Termista II, were summarized as one micro region due to their comparable geology and ecological conditions, despite being so distant to one another. Both sites are located near rivers in landscapes that are largely dominated by Pliocene to Eocene sediments (Fig. 3.6). Less than 20 km from the site of Olennii there are mountainous areas predominantly made up of Jurassic and Cretaceous rocks with metamorphic rocks occurring further into the mountain ranges. Less than 100 km away from Sukhaya Termista II is a hilly region of Palaeocene and Cretaceous rocks.

Olennii

Olennii is located in the Kalininskii region in the district of Krasnodar. The site is in the Kuban region north of the Caucasus Mountains. A. Gei excavated the group of three kurgans in 1987. Kurgans 1 and 2 have similar dimensions with diameters of approximately 30 m. Kurgan 3 was already destroyed but its diameter is thought originally to have been about 40 m. The preserved heights of the kurgans were

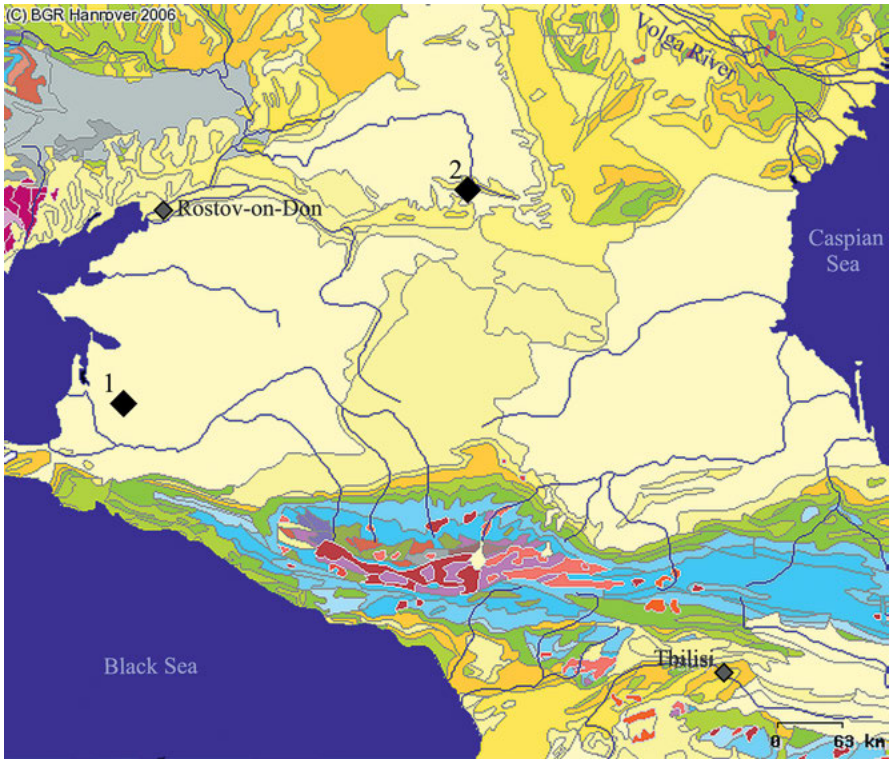


Fig. 3.6 | Geological map (based on Asch, 2005; scale 4.067.875) including sample sites in the Caspian steppe and the Kuban region: 1 Olennii, 2 Sukhaya Termista.

Geological Age:
Cenozoic: Pliocene-Palaeocene (yellow)
Mesozoic: Cretaceous (green), Jurassic (blue), Triassic (purple)
Palaeozoic: Permian (auburn), Carboniferous (grey)
Precambrian: Proterozoic (dark pink), Archaean (light pink)

Magmatic rocks: Cenozoic-Proterozoic plutonite (red)

between 0.8 m and 2.5 m. 14 burials of different time periods were discovered in kurgan 3, 21 burials in kurgan 1 and 35 burials in kurgan 2. Six graves were sampled: grave 21 from kurgan 1, graves 25, 26 and 35 from kurgan 2 and graves 3 and 14 from kurgan 3. They all date to the Novotitarovskaya culture and share several characteristics. The rectangular burial pits have similar dimensions and are mainly oriented W–E. With the exception of grave 3.14 all graves are covered by wood. The individuals are buried in crouched positions, some on their back, and some on their right side. They are mainly double burials. Four of the sampled individuals are infants and three are young adults. All the sampled graves contain ochre spread and organic mats. Grave goods vary from being rather poor to containing a large number of burial objects including wagon parts, ceramic vessels, spiral rings probably made of copper, bone beads and further bone objects, an animal skull and animal bones.

Due to the fact that four individuals were small infants, deciduous teeth were sampled. This was the second deciduous molar for the skeletons in graves 1.21, 2.25, 2.35 a, b. The second permanent molar was analysed for grave 3.3, the third permanent molar for grave 2.26 and a canine for grave 3.14. In the absence of any reference material three dentine samples were analysed to establish local strontium values.

Sukhaya Termista II

Sukhaya Termista II is located in the vicinity of the village of Remontnoe in the district Rostov. The site consists of five burial mounds in a line, three of which were still visible at the time of excavation. They were built on a terrace of the river Dyurak-Sal. N. I. Shishlina excavated two of the kurgans in 2008. Kurgan 1 measured 40 m to 45 m and had a height of 1.1 m. It contained five graves, three of them dated to the Early Catacomb culture. Kurgan 3 was much smaller in scale with a 36 m to 23 m diameter and a preserved height of 1.5 m. A large number of medieval burials were excavated as well as one grave dating to the Early Catacomb culture. All four sampled burials, graves 2, 3 and 5 from kurgan 1 and grave 20 from kurgan 3, belong to the Early Catacomb culture. All are of oval shape with a main orientation of SE–NW. Three of the four graves were of single burials. Grave 2 is the primary burial of kurgan 1; the primary burial of kurgan 3 is thought to have been destroyed. The individuals were mostly placed in extended supine positions. Graves either contained no burial objects or objects like ceramic vessels, bronze jewellery, red ochre pieces and some body parts were stained with ochre.

The first and third molars were selected for strontium and oxygen isotope analyses. In the case of the individual in grave 1.5, a first and a second molar were analysed. To establish the local $^{87}Sr/^{86}Sr$ range, the tooth enamel of one cattle tooth, the complete teeth of four recent rodents, one sediment sample and three human bones were used for analysis.

3.3 Iron Age

3.3.1 North Pontic region

Five sites dating to the Scythian period, Alexandropol', Babina Mogila, Drana Kokhta, Ordzhonikidze in the district of Dniepropetrovsk and Zolotaya Balka in the district of Cherson, provided 21 sampled individuals. The sites are located within a radius of approximately 50 km west of the River Dnieper. This area is a steppe-like plain that is geologically homogenous with a mixture of Proterozoic plutonites and Archaean metamorphic rock outcrops alternating with Cenozoic sediments (Fig. 3.7).

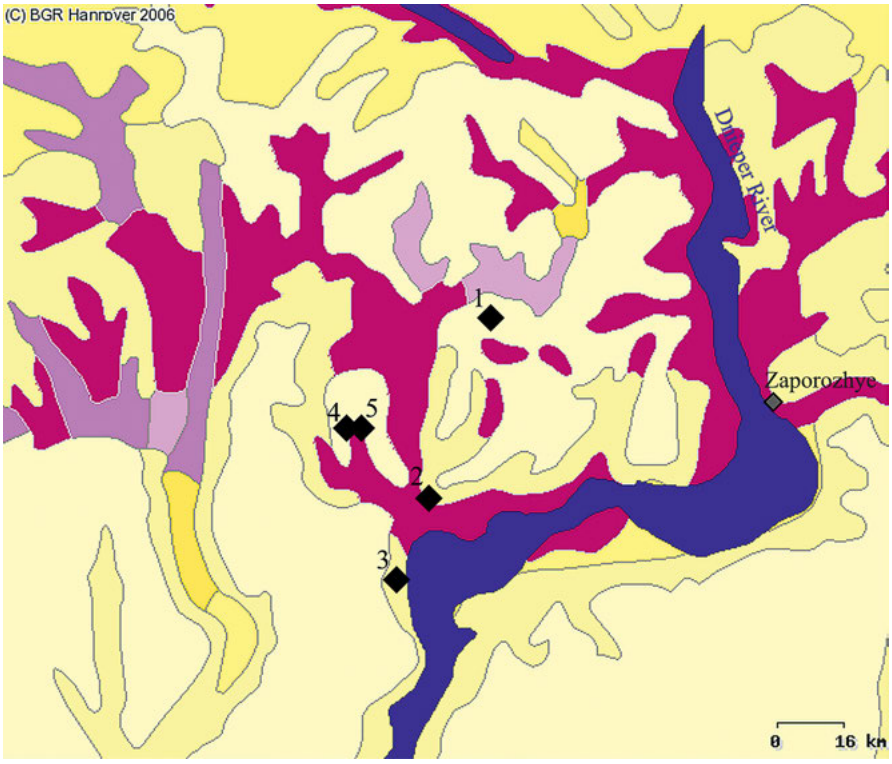


Fig. 3.7 | Geological map (based on Asch, 2005; scale 1.016.969) including sample sites in the North Pontic: 1 Alexandropol', 2 Ordzhonikidze, 3 Zolotaya Balka, 4 Drana Kokhta, 5 Babina Mogila.

Geological Age:
Cenozoic: Pliocene-Eocene (yellow)
Precambrian: Proterozoic (dark pink), Archaean (light pink)

Magmatic rocks: Proterozoic plutonite (reddish pink)

Alexandropol'

Alexandropol' is situated in southern central Ukraine, in the Solonianskii region. The single burial mound of Alexandropol' or Lugovaia Mogila has a diameter of 100 m and a height of 21 m and is one of the most impressive Scythian monuments (Polin/Daragan, 2011, 189). Excavations of the central burial took place in the 1850s. The grave, already robbed at that time, contained the skeletal remains of two male individuals and a horse. Excavations at the edges of the kurgan were undertaken by S. Polin in the first decade of the 3rd millennium, which led to the discovery of eleven secondary burials in the area of a feasting site. Five of these secondary burials, all considered to be contemporary with the primary burial and dating to the 3rd quarter of the 4th century BC (Polin/Daragan 2011, 201, 213), were analysed. The pits were oriented to the W and SW. The skeletons, all of them male and mainly adult, were buried in supine positions. The remains of a *symposium* or feasting activities were found in addition to grave goods that unfortunately cannot be assigned to specific graves.

Strontium and oxygen isotope analyses were undertaken on the first molars of individuals in graves 4 and 6, and the third molars of individuals in graves 1, 3 and 8. Three dentine samples were taken as reference material to establish a local signature in addition to a recent rodent tooth and three sediment samples from various parts of the burial mound.

Babina Mogila

Babina Mogila is located in the region of Apostolovo. Most of the 11 burial mounds on the site are damaged or destroyed by agricultural activity. Two of the kurgans date to the Bronze Age, the rest to the Scythian period. The Babina Mogila kurgan has a diameter of 60 m and a height of 8.15 m. It contains one complex central burial with three chambers, in which seven individuals were buried. The kurgan was already looted when excavations took place in 1986 under the supervision of S. Polin. Samples were taken from a 'servant in the *dromos*' of burial chamber 1 and from the central burial, grave 3, which contains a trapezoid chamber with a rectangular entrance. In burial chamber 1, fragments of more than 91 ceramic vessels including Greek imports, bronze wagon fittings and further objects that all belong to the main burial were found. The amphora stamps date the burials to the 4th century BC.

Strontium and oxygen isotope analyses were undertaken on the first molars of the two individuals. In the absence of other reference material, dentine samples were used to establish a local signature.

Drana Kokhta

Drana Kokhta, or Zheltokamenka, is also situated in the region Apostolovo. The kurgan, with a diameter of 76 m and a height of 9.2 m, is part of a group of 15 burial mounds dating to the Bronze and Iron Age periods. It contained four Scythian and one medieval grave. Excavations by B. N. Mozolevskii took place in 1974 and 1975. The burials were placed in a complex catacomb-*dromos* construction with niche annexes. Altogether, six individuals were buried in the burial complex, three adults together with three children. Samples were taken from the skeleton of a male adult buried in the central catacomb and a juvenile female individual buried in niche 5, an annex of the catacomb. Two horse burials including equipment were given as grave goods to the male individual, while the grave of the single burial contained jewellery, bronze earrings, a bead necklace, a bangle and tongs made of iron.

Strontium and oxygen isotope analyses were undertaken on third molars of the two individuals. In the absence of any other reference material, dentine samples from both individuals were used to establish a local signature.

Ordzhonikidze

The site is located in the Nikopol' region. Excavations were undertaken in 1998 and 2007 by S. Polin. Two kurgan groups, each with eleven mounds, were found. Six individuals were sampled from five graves. In kurgan 15, the only burial mound with larger dimensions, graves 1 and 2 are considered to be the primary burials and had complex catacomb systems with *dromoi*. The sampled individuals were mainly buried in supine positions, often as double burials, and were all males and females of older age. Although grave goods were found, there is no detailed information on quantity or grave affiliation. All the graves can be dated to the 4th century BC.

Strontium and oxygen isotope analyses were undertaken on the second molars from graves 15.1, 32.4 (the female), and 33.1 and third molars from graves 15.2, 33.3 and 32.4. Two dentine samples and an animal bone were analysed to establish the local signature.

Zolotaya Balka

The group of burial mounds in the Novovorontsovskii region contained 22 kurgans and was excavated by S. Polin in 1982. Grave 1 in kurgan 13, graves 1, 2 and 3 in kurgan 15 and grave 1 in kurgan 22 were sampled. Amphora stamps date all the burials to the 4th century BC. The individuals were placed in catacombs with varying orientations. All burials are primary burials of varying age and sex. Three of the skel-

etons were buried in supine positions. All graves contained burial objects, but no detailed information is given.

Strontium and oxygen isotope analyses were undertaken on the first molars from the individuals in graves 13.1 and both individuals in 15.1. A second molar was sampled from skeleton 15.3 and third molars were sampled from the individuals in graves 15.2 and 22.1. In the absence of other reference material, two dentine samples were taken in order to establish the local signature.

3.3.2 Central Asia: Berel'

Berel' is situated in the northeastern part of Kazakhstan in the region Katon-Karagai and the province Uryl. The site is located in the Altai Mountains in the Bukhtarma valley near the modern village of Berel'. The Altai Mountains are geologically mixed, this part of the Altai being predominantly composed by Ordovician rocks (Nechoroschew, 1966, 19–20). Palaeozoic rocks, of Cambrian to Permian age, dominate the geology of the site and the wider environs of Berel'. Outcrops of Proterozoic rocks are located further to the north, while Cenozoic sediments occur to the south (Fig. 3.8) (Naliwikin, 1959, supplement 6; Nechoroschew, 1966, fig. 18).

The site consists of several dozen Scythian burial mounds, which belong to the Pazyryk culture. V. V. Radloff undertook excavations on the necropolis in the middle of the 19th century, and the site was again excavated in recent years (cf. Samashev, 2011). Some of the kurgans were aligned, while others were offset. Kurgan 11 was published in detail and can be regarded as a good example for the burial rite.

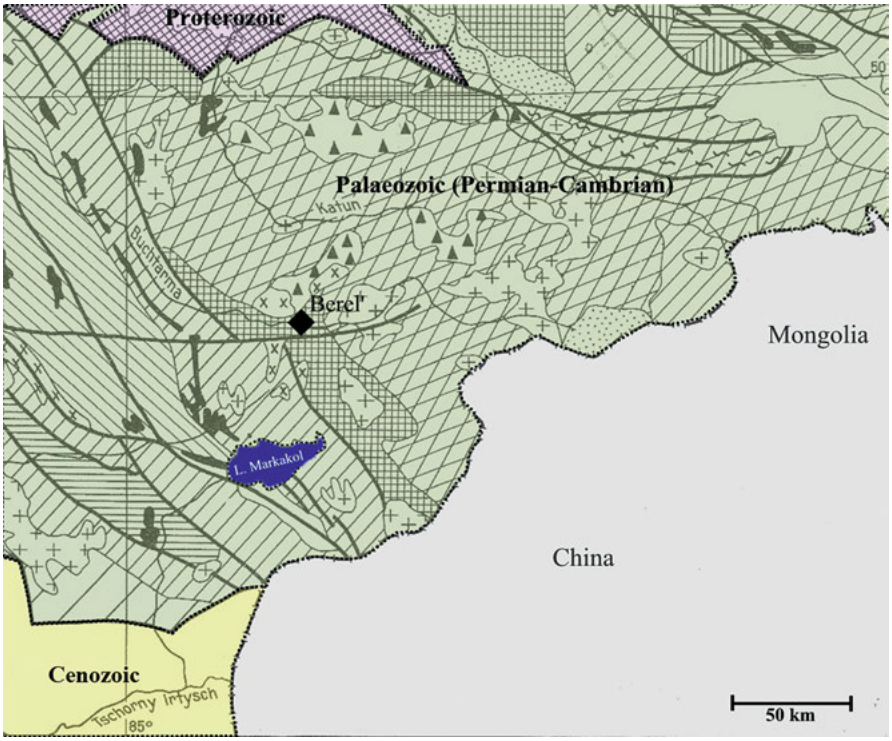


Fig. 3.8 | Geological map (modified after Nechoroschew, 1966, fig. 18) showing the location of Berel', Kazakhstan.

The mound had a diameter of 23 m and was erected over a rectangular trench 6 m deep. The stone tumulus covered several frozen graves, which led to exceptionally good preservation. The funeral chamber consisted of a wooden sarcophagus containing the primary burial. A secondary burial was placed in the same funeral chamber. As well as a large number of funeral objects, 13 horses were sacrificed and placed in the grave with their complete equipment and adornment.

Six human individuals and five horses were sampled. Samples from human teeth were taken from primary burials, both male and female, in kurgans 9, 10, 16, 32, 34 and 72, and date to the 4th to the 3rd centuries BC. All sampled skeletons were single, supine in wooden chambers, mainly oriented NE–SW. The kurgans contained up to ten horse offerings as well as exquisite burial objects in high numbers. Five horses from five kurgans (burial mounds 9, 10, 11, 18 and 23) were sampled. These mounds contained varying numbers of horses, between one and 13 compared to one or two humans. All of the horses belonged to the primary burials and wore equine equipment. Some of the objects were richly ornamented.

Strontium and oxygen isotope analyses were undertaken on an incisor from kurgan 34, a first premolar from kurgan 10 and third molars from the individuals in kurgans 9, 32 and 72. Each horse tooth was sampled in three places; one sample was taken from the cusp, a second from the cervix of the tooth enamel and the third sample was a complete vertical section. Dentine samples from all human and faunal individuals and two sediment samples from kurgans 8 and 75 were used to establish the local Sr signature.

4 Mobility and Migration

4.1 Introduction

The key objective of this study is the characterisation of mobility, mobility patterns and possible migrations of the Western Eurasian steppe populations during the Eneolithic period, the Bronze Age and the Iron Age period. M. Frachetti (2011, 197) remarked: 'Migration has a deep explanatory history in Central Eurasia', but while multiple studies have concentrated on finding evidence for mobile individuals or migrations in archaeological contexts, the theory behind population movements or the movement of single human individuals in prehistory has received less attention. The works of D. W. Anthony (especially Anthony, 1990; but also 1986; 1992; 2000), in which he adapts migration theories deriving from social sciences to an archaeological context, are of special importance, since he regards the impact of the Yamnaya people on southeast Europe as a key example of migration (see also critical replies by Telegin, 1987; Chapman/Dolukhanov, 1992). In German archaeology, S. Burmeister and R. Prien are the most prominent recent proponents of a theoretical approach to mobility and migration in the past (Burmeister, 1998; 2000; Prien, 2005). The volume 'The archaeology of mobility', edited by H. Barnard and W. Wendrich (2008), focused on theorizing mobility and brought it together with archaeological and modern case studies and a recent overview over migration concepts in Eurasian steppe archaeology is provided by M. Frachetti (2011). Despite the fact that the number of isotope studies focusing on the mobility of individuals or groups has expanded vastly in the last two decades, with the analysis of strontium, oxygen, lead, sulphur, neodymium and hydrogen isotopes for example, the relevant theories on mobility and migration are commonly only briefly touched upon.

Chapter 4 starts with a general introduction of mobility and migration theories in archaeological research. Then, the methods of the applied stable isotope analyses, namely strontium and oxygen isotope analyses, are explained and results of these analyses are presented and discussed. The chapter's structure primarily according to research methods rather than sites requires a very high number of figures and some repetitions to keep the single steps comprehensible. In order to keep things neat, single individuals were not labelled in the figures and error bars, which were mostly negligible and smaller than the symbols, were not added to the graphs. The results including standard errors are listed in the Appendix catalogues A, B and C. Furthermore, despite the difficulties regarding first permanent molars, they were included in the data evaluation due to restricted sample sizes. This section is followed by a general discussion and conclusion of the presented results with regard to the research questions.

4.2 Theories on mobility and migration

4.2.1 History of research in mobility and migration theories in prehistoric archaeology

The research history of the underlying theories behind mobility and migration in prehistory has been described in detail by many (cf. Anthony, 1990, 896–897; Burmeister, 2000, 539–540; Prien, 2005, 11–48) and is briefly summarized below. In German archaeology, discussions focusing on the reasons for cultural change started as early as the late 19th century, when L. Frobenius first introduced the theory

of *Kulturkreise* in ethnology (1898). The concepts of *Kulturkreislehre* and *Kulturprovinzen* were taken up and refined by the early German diffusionists like F. Ratzel (1899) and F. Graebner (1911). Building on this theoretical framework G. Kossina (1911) developed his *Siedlungsarchäologische Methode*, which was for many years a formative concept arising from the hypothesis that archaeological cultures equal peoples. Subsequently, in the first half of the 20th century, migration and diffusion were the most popular explanations for changes in material culture not only in German archaeology but also in the Anglophone countries. In this context, V. G. Childe (1925; 1929; 1958) used the spread of Neolithic farming as an example to put forward his theory that migration and diffusion in conjunction act as primary factors in social evolution. In the 1950s, migration and methods to identify migration in the archaeological record became increasingly popular in American archaeology (for example Rouse, 1958). In the following, migrations were mainly neglected by Anglo-American archaeologists and the proponents of the New Archaeology like Binford (1965) and Myhre and Myhre (1972) refused migration as an explanatory model. Diffusion of archaeological material culture was mainly associated with other models (e.g. Clark, 1966) and migration hypotheses in archaeology were widely questioned (e.g. Renfrew, 1972; 1973). The proof of migrations and its limitations, however, became interesting again, represented by the studies of e.g. Adams et al. (1978), Ammerman and Cavalli-Sforza (1973; 1979; 1984) and Rouse (1986) and the topic was reintroduced by postprocessual archaeology to the Anglo-American archaeological debate. The works of the late 1980s and the following decade, for example Kristiansen (1989), Chapman and Hamerow (1997), and especially Anthony (1986; 1990; 1997; 2007), were of huge significance and made migration a serious explanatory model again. D. W. Anthony is not only one of the most prominent representatives in recent archaeological migration research, but also focused on the Yamnaya impact on Eastern Europe which, according to him, is an excellent example of a prehistoric migration. In Germany, models were only adapted and refined at the end of the 20th century (Härke, 1997), and resulted in the influential works of St. Burmeister (1998; 2000) and R. Prien (2005). The revival of migration and mobility as explanatory models in archaeological research is also evident in a number of conferences on this topic that took place in the 1990s (cf. Knipper, 2004, 636). This new interest is certainly partly, although not exclusively, related to scientific progress in the introduction of genetic and stable isotope analysis in archaeology.

4.2.2 Mobility

4.2.2.1 Definition

'Mobility' generally refers to the shift of single individuals or groups of people between two units or positions, either socially or spatially (Kottwitz, 1971, 7; Burmeister, 2013, 36–37). Social mobility is not subject of the present study and is therefore excluded from discussion. Spatial mobility can refer to the movement of humans, objects, or ideas (Steuer, 2001, 118–19; Knipper, 2004, 632). In the frame of spatial mobility, Th. Champion (Champion, 1990, 214) discerns two mobility types: the regular mobility in non-sedentary or partly sedentary societies, and secondly the irregular mobility in sedentary communities. Within mobility in non- or partly sedentary societies, mobility can be defined as the 'capacity and need for movement from place to place' (Wendrich/Barnard, 2008, 5). The activities of these individuals or communities are based on or connected to movements, even if periods of non-movement are evident. The authors characterize mobility in terms of the moment, such as the period of movement and its

length, the movement range and pattern, the motivation (for example external factors, or identity), and the 'segment', meaning the part of the population that is moving (Wendrich/Barnard, 2008, 8, 9 table 1.3). Burmeister (2013) refers to the concept of action space. Action spaces are created at different locations by individual (mobile) activities and can either be shifted or exchanged by movements (Franz, 1984, 32–33; Burmeister, 2013, 37).

4.2.2.2 Mobility models

In general, there are not only strictly nomadic or entirely settled lifeways, but a variety of different degrees of mobility exist between sedentarism on the one hand and nomadism on the other hand. In addition, there is always some form of interaction between nomadic communities and settled or agrarian societies (Khazanov, 1984; Popova, 2009, 296–298). In sedentary communities, members generally inhabit the same place year-round and life-long, but most individuals are sporadically mobile with short-term stays at different places (Wendrich/Barnard, 2008, 11), for example mobile single individuals and subgroups such as transhumant herders, craftsmen and traders. Transitional forms of mobility in sedentary communities, in association with animal husbandry for example, are pronounced in semi-sedentary pastoralism, in distant-pastures husbandry and in transhumance (Knipper, 2004, 658).

Non-sedentary communities are always based on mobility but exhibit different degrees of mobility ranging from a totally nomadic lifestyle in their most extreme form, to semi-nomadic or even semi-sedentary lifestyles involving periodic absences at the other end of the scale. It was suggested that the difference between nomadism and semi-nomadism is that nomadic mobility is connected with movements to instable resources, whereas semi-nomadism is based on stable resources (Koryakova/Hanks, 2006, 277 citing Петров, 1981). Not all individuals in non-sedentary societies must be mobile all time, nor do non-sedentary societies have to be invariably mobile. Some hunter-gatherer societies, for example, follow specific, often seasonal, movement patterns. Furthermore, not all members of mobile societies necessarily follow the same forms of mobility since segments of the community might practice stockbreeding, while another part lives a semi-nomadic or nomadic lifestyle (Koryakova/Epimakhov, 2007, 208–209).

R. Cribb (1991) distinguishes between the nomadic mobility of pastoral nomads and hunter-gatherer societies on the basis of the motivation for mobility, which is either determined by humans or animals. Since pastoralism is not equivalent to nomadism, Cribb is able to distinguish gradations of pastoralism, where a higher level of pastoralism involves a higher level of nomadism (Cribb, 1991, 16). According to Cribb pastoral nomadism is characterised by a productive economy, a mobility influenced by grazing resources for animals and following a simple but unstable pattern, a human consumption that is independent of the animals, and a constrained scatter of archaeological remains. There are ethnographic studies with deviating patterns, however, which disagree with Cribb's characterisation (Wendrich/Barnard, 2008, 6, table 1.2).

In the context of their definition (see Chapter 4.2.2.1), W. Wendrich and H. Barnard differentiate mobility into four variants (Wendrich/Barnard, 2008, 5–6, fig. 1.2) (Fig. 4.1). In the first variant the entire community moves following a distinct pattern. According to the second type, the complete group moves from one resource to the next, as in the case of raw material resources. While type 1 mobile groups follow a fixed cycle, they might move between pastures in a yearly cycle for example, type 2 mobile groups do not follow a systematic pattern. The third and fourth variants are applicable to com-

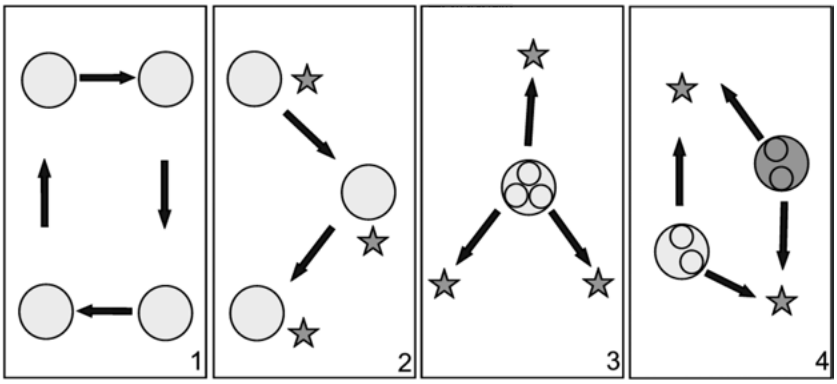


Fig. 4.1 | General schemes of mobility patterns, where circles indicate social groups with small inner circles representing group segments and stars symbolize resources or pastures (modified after Wendrich/Barnard, 2008, 5 fig. 1.2).

munities with mobile segments, while the communities themselves are settled. In type 3 one or several parts of the community exploit various resources and travel back and forth between the resources and the base camp, like herders moving to summer pastures and returning to the remaining settled group during winter. Type 4 describes the exploitation of the same resources by segments of different groups. At the same time subgroups can travel backwards and forwards to various resources. In this model, the time span of the stationary periods is not defined and can vary from several hours to several years, for example hunting versus herding on pastures.

On the basis of their relevance to the periods and regions under discussion, some of the types of mobility are discussed below in more detail: The term 'nomadism' generally refers to non-sedentarism and can be expressed in different variants (Knipper, 2004, 657). Nomadism can be associated with different mobile economic strategies such as hunting and gathering but also pastoralism (Salzmann, 2002, 245; Frachetti, 2008a, 16). In consequence, 'nomadic pastoralism is most commonly understood as a social and economic strategy predominantly based in routined (such as seasonal) migratory management of domesticated herd animals' (Frachetti, 2008a, 15; see also Khazanov, 1984, 17). Koryakova and Epimakhov (2007, 204) give another definition of nomadic pastoralism, which they regard as a 'form of food-producing economy with extensive mobile stockbreeding, livestock management all year round with free-range grazing and without stables, and laying fodder for animals when most of the population periodically transmigrates with the flocks'. Crawford and Leonard (2002, 1–2) define nomadic pastoralists as 'populations that specialise in animal herding, which requires periodic movement for purposes of grazing', often bound to marginal environments like the steppes and provides an adaptation to those sparse resources. Cultivation is not a priority, and animal husbandry is the only economic basis for nomadic pastoralism. Reasons for migrating are to make the most efficient use of seasonal pastures, to reduce competition for resources and to avoid hazardous environments and the build up of parasites in pastures (Crawford/Leonard, 2002, 3).

'Semi-nomadic pastoralism' is based on extensive stock rearing with an intense mobility in association with shifts of pastures during summer and permanent stays in the winter months (Khazanov, 1984, 19). Movement patterns in summer can vary, being radial, vertical, or meridional movements for example, and are mainly influenced by ecological conditions. Since communities of the steppe and forest-steppe region prefer a natural water supply, movement routes are likely to be along rivers and

winter stays to be in river valleys. Traditional routes are usually only changed as a result of severe ecological crises (Koryakova/Epimakhov, 2007, 208 citing Масанов, 1995, 79–84). Winter residence durations can last up to several months and are characterised by limited activity and mobility (Koryakova/Epimakhov, 2007, 206). Agriculture and trade may supplement the rearing of livestock, which forms the primary economic means of existence. In semi-nomadic communities either one part of the community is settled and practices cultivation while another part practices animal husbandry or the entire community lives on both animal husbandry and cultivation and is settled for some months per year (Khazanov, 1984, 19–20; Wendrich/Barnard, 2008, 7). Semi-nomadic pastoralism is often associated with seasonal mobility. The degree of mobility is often influenced by the seasons as they affect resource availability, the type of agricultural activities possible and thus the duration of site's suitability for habitation (Kirsanow et al., 2008). One form of seasonal mobility is the seasonal movement with herds, the distant-pastures husbandry or transhumance. Horizontal transhumance, for example in the steppe plains, refers to seasonal movements at similar altitude (Wendrich/Barnard, 2008, 7–8), while vertical transhumance, e.g. in the Altai or the Carpathian Mountains, involves lowland stays in winter and upland pastures in summer. Kirsanow and colleagues, for example, explored pastoral nomadism in the Mongolian Gobi Desert. In general, winter camps can be distinguished from a seasonal movement during the warmer months. As the grazing resources are depleted every three to five weeks, the herd is moved to the next grazing point 5 to 10 km away (Kirsanow et al., 2008, 3161). A third form of transhumance in settled communities is the *Triftwirtschaft* (pasture economy) (Karmyčeva, 1981), where year-round herds are kept on pastures in the vicinity of the settlements during the day and in the settlements during the night.

4.2.2.3 Characteristic forms of mobility in the Eurasian steppe belt

In general, many prehistoric communities of the West Eurasian steppes followed a pattern of regular, usually seasonal, movements involving the whole community or parts of it. The late and final Eneolithic cultural communities of the steppes are characterised by manifold burial traditions (cf. Rassamakin, 1999; 2004), and settlement sites are attested for most parts of the steppes (see Rassamakin, 2004, 186–203; Kohl, 2007, 144). The archaeological and archaeozoological evidence at these sites provide a heterogeneous picture of the Eneolithic subsistence strategies, potentially associated with variations in mobility. Although there are hints to communities leading a settled way of life, the predominant economic interest was likely to be in animal husbandry, while crop cultivation (and hunting) was of minor importance. This is suggested by the finds of the lower layer of the Mikhailovka settlement in the Dnieper valley, for example (Anthony, 2007, 268; Shishlina, 2008, 225–226). The shift from this relatively settled lifestyle to a predominantly pastoralist one of domestic cattle, sheep, goats and horses is assumed to have happened in the Early Bronze Age, approximately at the end of the 4th or the transition to the 3rd millennium BC (Frachetti, 2008a, 20, 44). The paucity of the archaeological record, a combination of few known settlements with the limited evidence of agriculture activity, led to indirect evidence like the adoption of local ceramics and the introduction of wheeled transport being seen as the main indicators for a non-sedentary lifestyle of Early Bronze Age steppe communities. This has in turn led to intense discussion on the nature of nomadism or semi-nomadism in the prehistoric societies of the West Eurasian steppes (cf. e.g. Koryakova/Epimakhov, 2007, 215–216; Kaiser, 2010a, 195). Limited percentages of bone finds of domestic animals suggest that the Early Bronze Age steppe communities were

not entirely mobile, however (Parzinger, 1998, 470; Parzinger, 2006, 243). The natural environment of the steppes required the economy to adapt to arid climate conditions. An example of a mobile economic strategy as a response to unfavourable climate conditions is the nomadic pastoralism of the historical nomads in Kazakhstan, where the climatic conditions of the steppes and semi-deserts allowed only seasonal agricultural activities. Semi-nomadism, based on a mixture of herding and other agricultural activities occurs peripherally to this core zone of pure nomadic pastoralism in the climatically more temperate southern Urals and western Siberia (Koryakova/Epimakhov, 2007, 205 citing Масанов, 1995, 22–24). Most scholars assume a development of increasing mobility in association with semi-nomadic cattle herding in the late Eneolithic or Early Bronze Age that peaked with the fully nomadic economy of the Iron Age communities of the 1st millennium BC (Khazanov, 1994, 19–21, 94; Kohl, 2002, 165; Koryakova/Epimakhov, 2007, 209–210; Frachetti, 2008a, 19).

Archaeological investigation and ethnographic comparison suggest different patterns of mobile pastoralism for the prehistoric societies of the western steppes. A pattern of all year movement along short-distance routes from pastures near rivers in autumn and winter to watershed plateaus in spring was attested for the Yamnaya groups in the northwest Caspian steppe region (Shishlina, 2001a; Shishlina, 2004, 101–102; Kohl, 2002, 164). Based on the evidence of settlement sites at the Lower Volga river bank, Otchir-Gorieva (2002) suggested the Yamnaya economy – at least in this region – to be a combination of agriculture and animal herding (Otchir-Gorieva, 2002, 122–123; cf. Kohl, 2007, 160). While cyclical mobility patterns during the Yamnaya period were guided by the courses of rivers, the 'open steppe' was occupied in the following Catacomb grave time only (Shishlina/Hiebert, 1998; Shishlina, 2003, 360–363). Excavations of Catacomb culture sites in the North Caucasus showed that pastoral mobility was probably linked to climatic conditions and local patterns of mobility were dictated by seasonal variations of pasture resources, which resulted in the formation of pastoralist landscapes determined by the cyclical exploitation of river zones and the 'open steppe' (Shishlina, 2001a). According to Shishlina the reasons for the opening of the steppes were increased mobility including the use of horses, increased aridity and overexploitation of pastures (Kohl, 2002, 164–165; Shishlina, 2003, 360–363).

The Bronze Age camp sites investigated by N. I. Shishlina correspond to ethnographic parallels. Nomadic Kalmyk pastoralists inhabited the Caspian steppe from the 17th to the 20th centuries and moved year round in groups of one or two families and several wagons, spending the winter in permanent sites and the summer in camps spread over the entire steppe (Shishlina et al., 2008, 247). In dependence of water supply migratory cycles of recorded nomadic communities tend to follow river valleys in seasonal change between vegetation zones (Kohl, 2002, 164). The ranges of year round or seasonal mobility of ancient and recent pastoralist societies vary between a few and several hundred kilometres (Shnirelman et al., 1996; Ferret, 2009; Bendrey et al., in press). In general, vertical movements tend to follow shorter routes. Mobility on a smaller scale is attested for nomadic people in the Tuva region during the early 20th century who followed seasonal movement routes of 25 km to 60 km depending on herd sizes (Vainshtein, 1980, 83–103). Ethnographic evidence also exists for the herd management strategies of the Bashkir and Kazakh populations in the Trans-Ural and Western Siberia in the 19th century up to 15 small family units formed a group of dwellings. Living settled during winter, they moved periodically during the remaining year exploiting a certain range of pastures within a range of up to 50 km (Koryakova/Hanks, 2006, 278–279). Recent Turkic-speaking tribes, for example the Tuvinians and the Altaians, showed cyclical seasonal migration patterns, which were mostly vertical in direction. Pastures were strictly regimented and the natural conditions required a system of routes, in

which divergences from the system caused extreme social tensions (Bokovenko, 1995a, 255–256). Long annual migration routes are reported for modern pastoralists in the Mongolian Altai, for example, with annual migrations of more than 200 km (Vainshtein, 1980, 83–103; Bendrey, in press), but also in other part of the study region, namely southeastern Europe (Hänsel, 1998, 12).

4.2.3 Migration

4.2.3.1 Definition

'Migration' is one distinct manifestation of mobility. Sometimes the term is used synonymously with 'mobility' but in general opinion 'migration' is the long-term or permanent spatial change of residence either by one or by several individuals, parts of the community or the complete community (Mignon, 1993, 200; Prien, 2005, 10). As early as in 1930 V. G. Childe wrote: 'A culture moves bodily, i.e. when the whole complex of types, fashions and habits spreads into an area where the said forms of tools and weapons, artistic conventions and burial rites had not previously been generally current, we must admit that we a dealing with a migration' (Childe, 1930, 42). In a similar way Kearney (1986, 331) refers to migration as the 'movement of people through geographic space', involving a permanent relocation. This relocation might go along with a process of acculturation, single changes, for example in the subsistence strategy, or even the 'creation of an ethnic enclave at the destination' (Killgrove, 2010, 12). Another definition is given by G. A. Clark, in which migration is a 'relatively short-term, long-range process or even involves mass population movement' (Clark, 1994, 305). According to Myhre and Myhre (1972, 45) it needs at least two people to be in involved in the movement to another geographical area, either within a short or a long time and either on a small or a wide range. E. Neustupný and K. Kristiansen distinguish between the number of individuals that migrate together by referring to mobile entities (*mobile Einheiten*) (Neustupný, 1981, 115–116; Neustupný, 1983, 12; Kristiansen, 1989, 219), but migrations can also be distinguished spatially (short or long distance, etc.), temporally (permanent, long term, etc.), causally (voluntarily or involuntarily) and according to social composition (e.g. number of migrants) (Kröhnert, 2007).

4.2.3.2 Migration models

Migration theories, originally developed in sociology, provide the basis for the common models applied in archaeology. The most important models were discussed in great depth in Prien (2005, 12–23), and therefore will only be summarized here. R. Prien found three succeeding phases in sociological migration research: In the first phase, migration was broadly categorised. The second phase saw the development of macro-theoretical models and the third phase encompassed the establishment of micro behavioural models. While macro-theoretical models focus on large social units and systems, micro-behavioural models concentrate on motivations for migration. Some examples of these include the 'gravitation model', where the migration area is more attractive than the point of origin, 'ecological models' and 'push-pull models', where migration is the result of push, pull and additional factors.

One of the first people to develop a migration model was the geographer E. G. Ravenstein (1885; 1889), who was able to subdivide eleven laws of migration on the basis of migration patterns the United

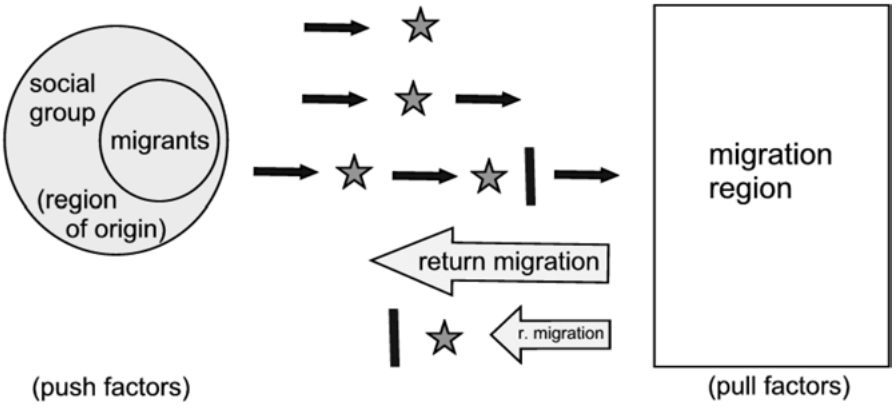


Fig. 4.2 | General scheme of a migration process (modified after Anthony, 1990, 900 fig. 1). Stars symbolize temporary stays or residences.

Kingdom and in the United States. His model strongly influenced gravity and economy models in following research. More than half a century later, W. Petersen (Petersen, 1958; 1972) classified migration into primitive migration, voluntary or free migration, forced migration, impelled migration and mass migration (Prien, 2005, 15). This model can be criticised for its categorisations, which make it difficult to compare the model with real migrations (Kröhnert, 2007). One of the first important micro-models on migration behaviour was E. S. Lee's regression analytical model (*regressionsanalytisches Modell*) (Lee, 1966), where he discussed four determinants for migration: push factors in the region of origin, pull factors in the migration region, possible obstacles, and personal factors. Only a small number of archaeological migration models exist. The model with the earliest influence is the 'wave of advance' model proposed by A. J. Ammermann and L. L. Cavalli-Sforza (1973; 1979; 1984) on the spread of the Neolithic into Europe. Further important models were developed by B. I. Rouse (1986), D. W. Anthony (1990) and St. Burmeister (2000). Rouse distinguished between local and inter-areal migrations. In Anthony's model both short-distance and long-distance migrations were discussed, but he also included push and pull factors as reasons for migrations. While Burmeister's model is similar to Anthony's, it is more focused on the chronological factors affecting migrations (Prien, 2005, 42–45).

D. W. Anthony's migration model focuses on the separation between short-distance and long-distance migration. Four phases of long-distance migration can be identified (Fig. 4.2) (Anthony, 1990, 902–904): First, single individuals or a small group of scouts leaves the region of origin to gain more information about possible migration areas. This phase of collecting information on social conditions and resource potentials and relaying it back to the potential migrants is also referred to as 'leapfrogging'. After a while, one or several groups move to the migration region of choice. This phase can include several migration waves or streams that tend to take well-defined routes indicated by a specific artefact distribution. After some time, there is a phase of establishment in the migration region. Return migration to the region of origin or to a preferred area of temporary stay may occur in this phase. Both on the way to the migration region and on the return there can be intervening obstacles that force the migrants to stay. According to Anthony, the following phases can be defined within the migration process: leapfrogging, migration streams and return migration. As an increased number of migrants is supposed to result in more evidence of the foreign material culture, the scout and migration stages leave few physical traces, while the phase of establishment is expected to be indicated by more material remains as well as settlements and burials. New objects and unknown traditions are brought back to the original place of resi-

dence through return migration (Anthony, 1990, 897). A mixture of original and adapted traditions can exist through all phases, but the occurrence of a cultural mixture is most probable during the phases of establishment and of return migration (Burmeister, 2000, 544–545; Prien, 2005, 318–319). The reasons for a segment of a community to leave its place of origin are subdivided into push factors and pull factors (Lee, 1966; Anthony, 1990, 899; Anthony, 1997, 22). Push factors such as climatic changes, extreme population growth resulting in overpopulation, social regulations and a shortage of resources are linked to negative conditions in the region of origin (Anthony, 1997, 23; Burmeister, 2000, 543–544). Pull factors, on the other hand, are favourable social or economic conditions in the destination area. Possible pull factors are the availability of raw material resources, short distances or easily accessible paths, for which information about the migration region is needed (Anthony, 1997, 24). Costs and the availability of transportation regularise the push and pull factors (Anthony 1990, 899; Anthony 1997, 22). The existence of wagons and draught animals, for example, made migrations and mobility less arduous.

In his article in 1997, Anthony follows Ch. Tilly (1978), who suggests a subdivision of migration into the following types: local, circular, chain, career, coerced migration, along with subsequent return-migration. Some of these types, however, correspond to mobility, also referred to as small-scale migration, rather than migration, also referred to as large-scale migration, since people leave their places of origin only for a certain amount of time in place of permanent or long-term relocations (Anthony, 1997, 26–27). This is also true, when he equates pastoral mobility with short-distance migration. Local and circular migrations, however, are most relevant in respect to the present study. Local migration, such as practiced by pastoral nomads for example, refers to a limited home range or social network range and can include both small and considerable distances. Pastoral nomads can also follow circular migration, which is defined by regular circulation outside the home range. Further examples of circular migrations are those associated with the exploitation of resources or trade.

St. Burmeister (1998; 2000) generally adopts and advances the model of migration processes proposed by Anthony (1990). His model for the North American colonists is premised on the concept of *Habitus* by P. Bourdieu (1993, 97–121). On this basis, Burmeister is able to differentiate between an internal and an external domain of the migrants. The *Habitus* originating in the past represents the private sphere, the internal domain, while the external domain is characterized by contact with local people, the material culture and the traditions of the migration area (Burmeister, 2000, 542). Burmeister holds the opinion that only macro-theoretical approaches are applicable in archaeological studies and archaeologists should look for proof of migration in the internal domain.

R. Prien (2005, 10) distinguishes between long-term migration, seasonal migration, nomadism and return migration and three time-related phases of a migration process: the scouting phase, the phase of establishment in the migration region and the return migration, fundamentally following Anthony. In addition, he separates mass migrations from migrations of the elite or specialists and displacement (Prien, 2005, 47–48, 318–322). In all cases, at least one segment of a population must live a relatively mobile way of life (Prien, 2005, 10).

4.2.3.3 Migration in the West Eurasian steppes

The Yamnaya groups of Eastern Europe have been regarded as a good example of migration for several decades, from the works of V. G. Childe and M. Gimbutas to the present. As early as in 1929 V. G. Childe referred to the ochre graves east of the river Tisza as having parallels in the South Russian steppes and as

being the results of intrusive cultures (Childe, 1929, 206–208). Later, M. Gimbutas (1956) proposed her influential simple invasion models to explain the spread of Eneolithic and Bronze Age steppe groups into Eastern Europe (cf. Anthony, 1986, Chapman/Dolukhanov, 1992 for critique). More than half a century later D. W. Anthony chose the Yamnaya culture as a key example to illustrate his migration model (Anthony, 1990, 905–908). According to him, the Yamnaya culture spread explosively to the east and west, which lead to a subsequent collapse of the Northwest and West Pontic settled cultures seen during the phases of scouting, migration stream and return migration. In the last couple of decades, however, new ^{14}C data were obtained that made Anthony's suggestions highly improbable (Kaiser, 2010a, 196) and most scholars do not share Anthony's point of view. Still several factors, such as the impact of population groups, the ability to prevail over large distances and the long-term evidence in the West Pontic region, qualify the Yamnaya groups as migrants (Heyd, in press). The use of wagons and draught animals would count as one factor that simplified large-scale movements (Anthony, 2007, 111, 322). Harrison and Heyd regard the transfer of the 'Yamnaya package' to the west of their original distribution area as a combination of circular and chain migration instead of a conventional migration or demic diffusion (Harrison/Heyd, 2007, 196). According to the number of Yamnaya graves in the Carpathian-Balkan region, however, a gradual immigration of smaller North Pontic groups is more probable (Ecsedy, 1979, 55; Kaiser, 2010a, 196). To put it straight, Kohl suggested the Early Bronze Age migrations from the Eurasian steppes, contrary to nomadic horse-riding nomads, might be associated with 'impoverished cowboys, who also knew how to cultivate crops, seeing a better life' (Kohl, 2002, 175).

As possible push factors for Early Bronze Age groups to leave the North Pontic steppes unfavourable climate conditions or even climate change might be considered. The aridity increases to the east of the steppes (Borisov, 1965, 130–131; Dolukhanov, 2009, 13), which is a possible reason to move westward rather than to the east (Koryakova/Epimakhov, 2007, 211). Anthony (1990, 908) suggests the reason for the movement of Yamnaya groups into the Eastern European plains could have been to exploit resources in the Hungarian Plain and, to a lesser degree, the metal ores in the Carpathian Mountains. In Anthony's opinion the trade of these resource goods lead to a return migration to the North Pontic region. Furthermore, he regards overgrazing as a possible push factor (Anthony, 2007, 300–306), but the contemporaneous decline of copper production in southeastern Europe and the vastness of the steppes make both arguments highly improbable (Chernykh, 1992, 54–57; Kaiser, 2010a, 199).

4.2.4 Scientific contribution to mobility and migration research in archaeology

No matter if Anthony is entirely right in saying that 'Cultures do not migrate. People do!' (Anthony, 1990, 908), the statement highlights the importance of analysis directly on the skeletal remains rather than only on the material culture, which is nothing but an indirect link to presumed human migration. This has been recognised several decades ago and while scientific methods such as the analysis of ancient DNA, stable isotopes, proteins and trace elements, have mainly focused on the development of the method in their pioneering stage, they are now increasingly, and almost routinely, applied to archaeological questions regarding mobility and migration (Alt, 2010, 12; Knipper, 2011, 188). Although traditional methods such as the evaluation of the cultural remains, typology and chronology are still predominant in archaeology, particularly in German archaeology, the scientific analysis of skeletal remains became an additional tool for archaeologists to collect information about the lifestyle, such as the diet, the economy, the mobility and the social structures of prehistoric communities (Alt, 2010, 10–11). The

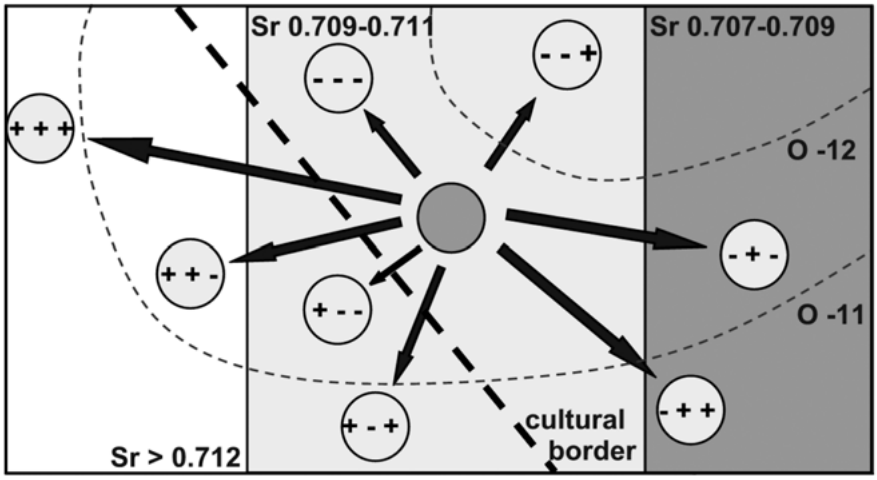


Fig. 4.3 | Evidence of migration derived from the combination of archaeology (± + +), strontium (+ ± +) and oxygen (+ + ±) isotope analyses (modified after Tütken, 2010, 45 fig. 6).

additional value of the combined application of traditional archaeological methods and stable isotope analyses to investigate mobility and migration in archaeological communities has appropriately been shown by Th. Tütken (Fig. 4.3). Tütken's model shows that besides the archaeological evidence stable isotope analysis provide further independent lines of evidence for the characterisation of 'mobile' or 'migrating' individuals. The identification of mobility, however, requires the crossing of borders between cultural or isotopic regions. Beyond all question, a multidirectional approach to the reasoning of non-local origins or non-settled lifeways of prehistoric humans and animals strengthens the validity of the research.

4.3 $^{87}Sr/^{86}Sr$ analysis

4.3.1 Basics

4.3.1.1 Introduction

Strontium belongs to the divalent alkaline-earth elements. It is close to and in the same group as calcium in the periodic table of elements, and thus has similar chemical properties and can substitute for calcium in body tissues (Schoeninger, 1979, 297; Burton et al., 1999, 609). Strontium has four stable isotopes; these are ^{84}Sr (with a relative abundance of 0.56 %), ^{86}Sr (9.86 %), ^{87}Sr (7.0 %) and ^{88}Sr (82.58 %). Stable isotopes do not decay over time, whereas radioactive or unstable isotopes do. ^{87}Sr is the beta decay product of the radioactive ^{87}Rb (Rubidium) and is therefore a radiogenic isotope. ^{87}Rb is radioactive and decays with a half-life of 4.88×10^{10} years (Faure, 1986, 119; Bentley, 2006, 137; Price, 2007, 427).

In strontium isotope analysis, the amount of ^{87}Sr in a sample is compared against the amount of ^{86}Sr under application of the following equation:

$$^{87}Sr/^{86}Sr = [(^{87}Sr/^{86}Sr_{sample} / {}^{87}Sr/^{86}Sr_{standard}) - 1] \times 1000$$

Ratios are expressed as $^{87}Sr/^{86}Sr$. Some stable isotope ratios vary in geochemical and biological systems on the basis of fractionation. In contrast to light isotopes such as oxygen, carbon and nitrogen, strontium, as a heavy isotope, shows no fractionation under normal conditions. This means that the relative proportion of strontium isotopes is not changed by natural processes like photosynthesis or heat (Price, 2007, 427). As a product of decay, the ^{87}Sr content of bedrock is related to its initial ^{87}Rb content and time. Consequently, $^{87}Sr/^{86}Sr$ ratios increase with the geological age of the bedrock. On average, $^{87}Sr/^{86}Sr$ values for rocks lie between 0.702 and 0.780 (Schweissing, 2004, 13; Tütken et al., 2004, 93–94). According to Knipper (2004, 629), the range is 0.703 and 0.750.

The $^{87}Sr/^{86}Sr$ signature of the geological bedrock is more or less unchanged by weathering processes as it breaks down to form sediments and soil. As the $^{87}Sr/^{86}Sr$ ratio is not affected by biological processes such as photosynthesis, plants will reflect the strontium signal of the sediments and geology below (Bentley, 2006, 136). Through the intake of food and water, this signature is then assimilated into the body tissues of animals and humans. Due to the fact that human teeth mineralize between early childhood and adolescence (see Chapter 2.2.2) and subsequently do not alter, the $^{87}Sr/^{86}Sr$ signature of the local bedrock at the time mineralisation took place is stored permanently in the tooth enamel of the individual. Although 75 % of the strontium taken up by the organism leaves the body without being stored, 99 % of the strontium that remains in the organism is stored in the hard tissues (Schweissing, 2004, 13). The relative abundance of ^{87}Sr, in teeth will vary with the age and the original Rb/Sr ratio of the bedrock (Bentley, 2006, 137–141). One factor that should be borne in mind, however, is that certain minerals within the bedrock will be more prone to weathering and therefore the isotopic composition of the whole rock does not necessarily always correlate with the isotopic signature that is transferred to soils and foods (Tütken et al., 2004, 94).

4.3.1.2 Strontium in human tooth and bone

To examine the enamel's resistance to post-mortem alteration, it is useful to determine ^{88}Sr and ^{87}Sr concentrations in both the enamel and the dentine samples. Tooth enamel is highly resistant to post-mortem diagenetic processes. Where $^{87}Sr/^{86}Sr$ ratios in dentine and enamel differ, the dentine usually has a higher strontium concentration as it has a greater tendency to react with the burial environment during diagenesis (Montgomery et al., 2003, 650; Pellegrini et al., 2008, 1718). Besides giving information on diagenetic alterations in tooth enamel and dentine, strontium concentrations can also provide information on dietary trophic levels. A diet based mainly on plant and dairy products leads to elevated strontium concentrations because plants are enriched in strontium, though, as described above, isotopic ratios are not affected (Montgomery, 2003, 651).

During the lifetime of an individual, concentrations of the trace element strontium are similar in bones and teeth (both the dentine and enamel), with ranges between 50 and 300 ppm in modern humans, though strontium concentrations of up to 600 ppm can occur (Montgomery et al., 2003, 651). In archaeological tooth and bone, strontium concentrations can be elevated but rarely exceed 1000 ppm (Pellegrini et al., 2008, 1718; Bocherens et al., 1994, 783). Generally, as described above, archaeological tooth enamel shows lower strontium concentrations than dentine and bone. Typical concentrations for enamel are 100 to 200 ppm (Hillson, 1996, 223). Schweissing mentions a wider range of 26 to 280 ppm (Schweissing, 2004, table 1). In dentine, there are strontium concentrations of 100 to 600 ppm and in bone ratios of 50 to 500 ppm (Bentley, 2006, 163). Higher concentrations in dentine are probably due to

post mortem uptake of Sr. Chiaradia (2003, 366), for example, found Sr concentrations in dentine of 950 ± 180 ppm. Though variations in Sr concentrations within a single human tooth are only minor, large differences between humans and places or sites exist due, for example, to varying geologies or to variations in the Rubidium content in the rocks and water (Hillson, 1996, 223).

4.3.1.3 Definition of the 'local' biologically available strontium

When interpreting the results of strontium isotope analysis, one needs to establish a data set representing the 'local signature', or the strontium available for uptake in the environment in the vicinity of the site. The definition of this 'biologically available' strontium has been the subject of major discussion since the method of strontium isotope analysis was introduced to archaeology. 'Biologically available' strontium refers to strontium that is incorporated into the hard tissues of the body through food and, to a lesser degree, water uptake (Knipper, 2004, 621). Various approaches to define the local range of biologically available strontium are discussed in numerous papers (a broad overview is given in Price et al., 2002; Knipper, 2004; Bentley, 2006; Evans et al., 2010).

When strontium isotope analysis was first introduced in archaeology, the body tissue most commonly used for analysis was bone, largely due to its availability. However, as has been mentioned above, bone is susceptible to post depositional alteration. While some authors considered a difference of 0.001 between the average $^{87}Sr/^{86}Sr$ ratios in bone and tooth enamel to be the appropriate limit value for the distinction between locals and non-locals (Grupe et al., 1997, 520; Schweissing/Grupe, 2000, 100; Price et al., 2004, 30), it became more common to use the average bone value ± 2 standard deviations (e.g. Price et al., 2002, 131). The diagenetic alteration in bone essentially represents the strontium signature of the surrounding burial environment, but this does not necessarily equal the biologically available $^{87}Sr/^{86}Sr$ at the site. Another factor to be considered is the slow turnover rate of bone, which means that the strontium signature present in the bone represents an average strontium uptake over decades and not necessarily the place of death (Knipper, 2004, 616–624).

Another well established initial approach is to look at the underlying geology. Before being used in archaeology, strontium isotope analysis was used in the earth sciences as a tool to date rock formations. Thus, there are published resources listing the $^{87}Sr/^{86}Sr$ ratio range typical of various rock types of a given age (for example Beard/Johnson, 2000). Using a geological map and access to these data, it is possible to establish a predicted range for local strontium ratios at almost any site (Knipper, 2004, 620–624). Unfortunately, bedrock often consists of a variety of rocks and minerals with differing $^{87}Sr/^{86}Sr$ ratios and the geology in the immediate environs of a site can vary at a smaller scale than most geological maps. Although direct $^{87}Sr/^{86}Sr$ measurement of the underlying geology in the form of bulk rock, bulk sediment samples or sediment leachates result in values that are similar to the biologically available strontium, they are not necessarily the same (Price et al., 2002, 122). After an initial phase of test-sampling bulk sediments, the use of soil leachates was found to be more effective. Different leachates were tested and it became clear that the best results were gained from using a combination of water leachates and acidic leachates to identify the biologically available strontium. In general, sediment leachates represent a better average of biologically available strontium than does bedrock. To add to the complexity, atmospheric $^{87}Sr/^{86}Sr$ ratios need to be taken into account in addition to the strontium signature in bedrock and sediments when estimating locally available strontium (Knipper, 2004, 617–620).

Water samples from rivers or lakes more often reflect the $^{87}Sr/^{86}Sr$ signature of the underlying geology rather than the biologically available strontium. Furthermore, small-scale geological variability and seasonal variations in the $^{87}Sr/^{86}Sr$ ratios of ground and surface water are responsible for variations in the $^{87}Sr/^{86}Sr$ signature in water samples (Knipper, 2004, 620). The analysis of faunal material is more promising. A range of studies have shown a lower variability in the $^{87}Sr/^{86}Sr$ ratios of local animal skeletal tissues at any one site compared to corresponding geological samples (example studies listed in Price et al., 2002, 122). Price et al. (2002, 124–125) recommend the use of small mammals such as rodents and snails, while Knipper suggests the sampling of domestic pig (Knipper, 2004, 622–624; Bentley/Knipper, 2005). The choice of comparative faunal remains should be guided by similarities in home ranges. Archaeological faunal material is certainly to be preferred but hard to find, and so more recent material is often selected. Even though contaminants like the use of fertilizers or modern atmospheric strontium may affect the $^{87}Sr/^{86}Sr$ values of modern mammals, they have the advantage of having limited home ranges and a mixed herbivorous plant diet. Price et al. (2002, 132) recommend 'the confidence limit for separating migrants and indigenous individuals be established using the mean of biologically available strontium isotope ratios (determined from animal samples) ± 2 standard deviations' (Price et al., 2002, 132). The suitability of this determination has been increasingly discussed over the last few years. The combined analysis of a variety of comparative sample material, i.e. faunal remains, sediment and rock leachates, water and vegetation material, creates a good picture of the biologically available $^{87}Sr/^{86}Sr$ at a site, even if results can be highly variable (Chenery et al., 2010, 152). The approach has been applied in a number of studies of the last decade, e.g. Price et al., 2002; Bentley et al., 2004; Evans/Tatham, 2004; Bentley/Knipper, 2005.

Usually, it is not only the strontium signature at the place of death, but also that of any potential migration areas, places of origin or mobility ranges that are of interest. Ideally, a systematic investigation of strontium signatures in the wider environment or supposed regions of origin is desirable (Knipper, 2004, 627), but most often research is restricted by limited funds and the researcher's own capacities and time. A first attempt of providing a biosphere $^{87}Sr/^{86}Sr$ map for Britain was published by Evans and colleagues (2010), which was based on the sampling of water, soil, plant, snail shells and dentine. Furthermore, publication of an increased number of isotopic studies will result, in the long-term, in more detailed strontium isotope mapping which will in turn help to correlate results of recent and earlier studies.

Another approach is the definition of the local $^{87}Sr/^{86}Sr$ signature using the Microsoft Excel macro Isoplot, as Vohberger (2011). Using Isoplot, a robust mean and limit values of radiogenic isotopes such as strontium can be calculated on the basis of the data itself to limit the local value range and thus no external references are needed. Outliers are calculated and eliminated, and marginal values are hence less important. However, this rather advanced approach is not easy to apply on small sample sizes (Vohberger, 2011, 97–98).

In the absence of other reference material, an estimate of the local soil strontium values obtained from diagenetically altered dentine can be used to identify local and non-local individuals and hence investigate migratory behaviour at the sites (Beard/Johnson, 2000; Montgomery et al., 2007). In contrast to tooth enamel, the less crystalline dentine is more likely to react with the burial environment and is therefore a good material of use to estimate the local biologically available strontium (Pellegrini et al., 2008, 1715). Thus, no attempt was made to remove diagenetic strontium from the dentine samples as they were used as proxies for the mobile soil strontium (as it was shown in Budd et al., 2000; Trickett et al., 2003).

Table 4.1 | Teeth, which were selected for $^{87}Sr/^{86}Sr$ analysis in tooth enamel, arranged according to their region of burial.

site	incisor	canine	premolar 1	premolar 2	deciduous molar 2	molar 1	molar 2	molar 3
Eneolithic and Bronze Age								
Bulgaria						25	4	7
Hungary				2		6	12	5
Ukraine						22	23	20
Russia		1			4	15	7	7
Iron Age								
Ukraine						7	4	10
Kazakhstan	1		1			1		5
n total	**1**	**1**	**1**	**2**	**4**	**76**	**50**	**54**

4.3.2 Material

The principle of focusing on micro regions across the whole study area guided the selection of sampling sites. Samples were taken from Eneolithic and Bronze Age sites in modern Bulgaria, Hungary, Ukraine and Russia as well as from sites dating to the Scythian period in Ukraine and Kazakhstan. The sample selection was constrained by the patchy nature of archaeological samples in sound contexts. In consequence, statistical analysis was challenging, given the variability of the number of samples per site and the number of sites per sampled region. 189 human teeth were sampled for $^{87}Sr/^{86}Sr$ analysis (Table 4.1), equating to 142 human individuals. 50 individuals were sampled in duplicate, and one individual in triplicate. Where possible, first and third molars or first and second molars were selected. First and third molars were sampled from 17 individuals while first and second molars could be sampled from 21 individuals. In most cases, however, the selection of teeth depended on availability. Thus, the sampling strategy may appear more random than it actually was.

In addition to the human samples, the tooth enamel of five horses from Berel' were selected for analysis. 105 dentine samples, 13 bone and 40 further reference samples were selected to establish the 'local' biologically available strontium range. Figure 4.4 shows the advantages of duplicate tooth sampling. In the present study, one of the most severe problems is the potential similarity in the geology of the place of birth and death. When the $^{87}Sr/^{86}Sr$ ratio of the first molar (M1) of this hypothetical individual is compared to the local signature of biologically available $^{87}Sr/^{86}Sr$ at the place of death, no movement will be visible even though in this example, the hypothetical individual has moved a significant distance. Samples from the third molar (M3) could be taken to explore the possibility that this individual was mobile during childhood and adolescence.

The analysis of tooth enamel on its own does not help to distinguish between 'local' and 'non-local' or sedentary and more mobile individuals. In order to interpret the findings, the $^{87}Sr/^{86}Sr$ ratio range of locally biologically available strontium needs to be defined. There are several ways to determine the expected local or more precisely regional $^{87}Sr/^{86}Sr$ ratio. The choice of baseline samples is not ideal, but the selection was restricted by the availability of suitable samples at each site. According to their availability, one or several soil and plant reference samples together with recent and archaeological fauna

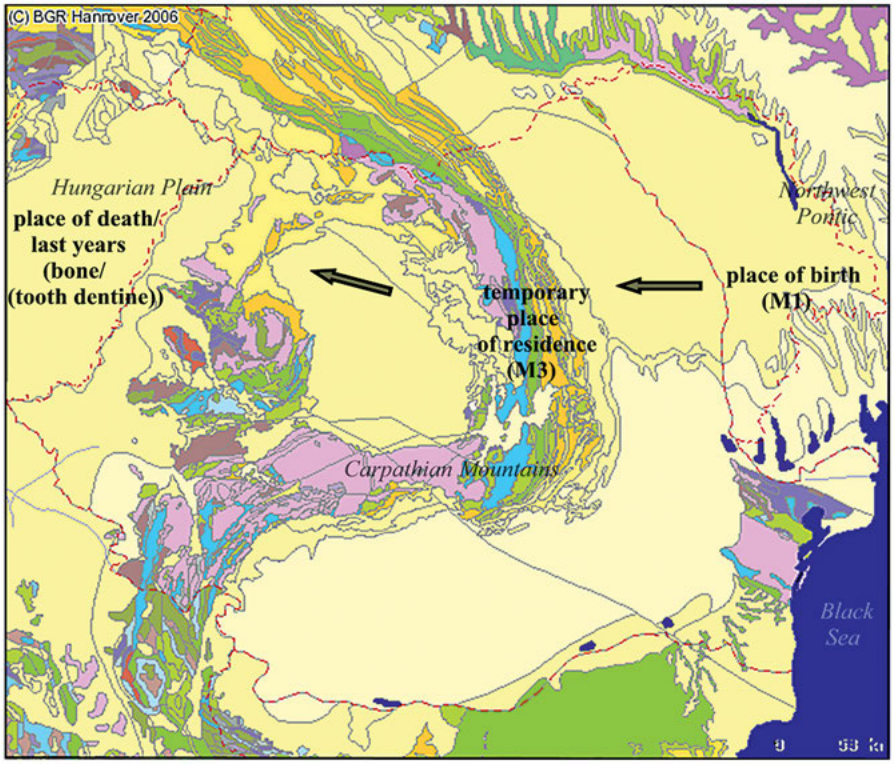


Fig. 4.4 | Potential lifetime mobility: A hypothetical individual moved from the North Pontic to the Carpathian Basin, two regions that do not differ significantly in their geological composition. It stayed temporarily in the Carpathian Mountains while its third molar was mineralizing.

were collected from Benkovski, Boyanovo, Ovchartsi, Smyadovo (Bulgaria), Sárrétudvari-Őrhalom and Kétegyháza (Hungary), Kirovograd, Peshtchanka, Shakhta Stepnaya, Vinogradnoe (Ukraine), Kalinovka I, Sukhaya Termista II (Russia), and Berel' (Kazakhstan). Only dentine and human bone were available from the remaining sites in Hungary, Nevskoe (Ukraine), the sites in the Volga region and Olennii (Russia). Following a conservative approach, an envelope of ± 2 standard deviations was added to the mean value of the references.

4.3.3 Methods

4.3.3.1 Methodology for tooth enamel samples

Samples were prepared in the laboratory facilities of the Department of Archaeology and Anthropology at the University of Bristol. Sample preparation follows the marginally adjusted methodology as described in Haack et al., 2008, 18230–18231 and Cahill Wilson et al., 2012. The steps of the methodology are shown in Table 4.2.

First, a longitudinal section of the tooth was cut using a flexible diamond-coated dental saw disc. Any adhering contaminants and dentine was removed using a tungsten carbide dental burr. The remaining enamel section of 3 to 30 mg was transferred to a glass vial and cleaned in high-purity water

Table 4.2 | TIMS Sr sample extraction and preparation procedure, column chemistry and mass spectrometry analysis following the Bristol Isotope Group protocol.

procedural steps		description
I sample preparation		
I.1.	separation of sample	longitudinal enamel section of 3–30 mg mechanically cut and cleaned
I.2.	cleaning and drying of enamel sample	sequential cleaning in high-purity water (MQ) in an ultrasonic bath (3 × 15 min.), rinsing between each cycle, oven-drying
II chemical procedure		
II.1.	weighing	weighing and transfer into pre-cleaned 7 ml Teflon beakers
II.2.	dissolution	dissolving in 3 ml of 7N HNO_3 on a hot plate (140°C, 12 hours), then vaporization on a hot plate (120°C)
II.3.		rinsing with concentrated HNO_3 and vaporization on a hot plate (120°C)
II.4.	preparation of stock sample solution	dissolving in 3N HNO_3, depending on the sample size: sample sizes below 6 mg dissolved in 0.5 ml, 6–15 mg in 1 ml and above 15 mg in 2 ml
II.5.	ultrasonic bath	ultrasonic bath for 15 minutes
II.6.	centrifugation	transfer into 2 ml centrifuge tubes, centrifugation with a rotation of 13.4 for 5 minutes
II.7.	preparation for column procedure	separation of aliquots representing ca. 3 mg of solid enamel for ion exchange column procedure
column procedure		
II.8.	column check	columns filled with 2 ml H_2O (MQ) to check functionality
II.9.	sequential washings	70 µl of Eichrom Sr Spec resin loaded onto column, 4 times alternate washing with 1 ml 3N HNO_3 and H_2O (MQ) to eliminate contaminants
II.10.	conditioning	conditioning with 150 µl 3N HNO_3
II.11.	sample addition	sample aliquot of 500 µl added
II.12.	Sr pick up	elution in 3 ml 3N HNO_3 to catch Sr and wash out Rb
II.13.	elution	elution in 1.5 ml H_2O (MQ), release in cleaned Teflon beakers
II.14.	column cleaning, sample vaporization	vaporization of collected sample on a hot plate, cleaning with 300 µl concentrated HNO_3 and second vaporization
III mass spectrometry analysis		
III.1.	filament loading	sampled loaded onto single rhenium filaments under elution in 10% HNO_3 and precondition of $TaCl_5$ and 10% H_3PO_4
III.2.	TIMS analysis	analysis of a batch of 15 samples, 5 external and 1 internal standards
III.3.	correction	correction of the results in respective to the NIST SRM 987 standard

(Milli-Q) in an ultrasonic bath for 5 minutes. This process was performed three times. Samples were then dried in an oven and transferred to the clean laboratory facilities in the Department of Earth Sciences, University of Bristol.

In the clean laboratory, samples were weighed into pre-cleaned 7 ml Teflon beakers, and left to dissolve in 3 ml 7N HNO_3 on a hot plate (140 °C) for 12 hours. After drying down, the beaker sides were rinsed with concentrated HNO_3 and dried down again on the hot plate (120 °C). The samples were then taken up in 3N HNO_3. The amount of 3N HNO_3 used varied according to sample weight; if the sample weight was below 6 mg, 0.5 ml of 3N HNO_3 was added, 1 ml 3N HNO_3 was used for a sample weight between 6 and 15 mg, and 2 ml 3N HNO_3 was used for samples above 15 mg. The dissolved sample was ultrasonicated for 15 minutes and pipetted into pre-cleaned 2 ml centrifuge tubes, then centrifuged for 5 minutes at 13.4 rotations. A 500 µl aliquot equalling 3 mg of the sample was decanted into a second minispin tube and made up to 0.5 ml with 3N HNO_3. Strontium was collected using conventional ion exchange chromatography. 70 µl of Eichrom Sr Spec resin was pipetted into columns and cleaned with alternate washes of 3N HNO_3 (x 4 reservoir volumes) and ultra-purity water (Milli-Q) (x 5 reservoir volumes) to eliminate contaminants. The resin was then preconditioned with 150 µl of 3N HNO_3. The sample aliquot was added and eluted in 3 ml of 3N HNO_3 and the strontium released with 1.5 ml H_2O (Milli-Q) and collected in cleaned Teflon beakers. The collected sample elution was dried down to a spot on a hot plate, cleaned with 300 µl of concentrated HNO_3 and dried down again.

The strontium spots were loaded on degassed single 'zone-refined' rhenium filaments preconditioned with 1 µl $TaCl_5$ and 1 µl H_2PO_4 to ensure a constant particle beam. Finally, strontium isotope composition was determined using a Thermo Finnigan Triton Thermal Ionization Mass Spectrometer (TIMS) at the laboratories of the Department of Earth Sciences of the University of Bristol, which is fitted with nine Faraday cup detectors and virtual amplifiers. Filaments were loaded onto a cartridge with capacity for 21 filaments and consisted of 15 samples, 5 external standards (NIST SRM 987) and 1 internal standard, the replicate analysis of cattle tooth WH 9.4. All samples were run to a precision of ± 0.00003 (2σ) or better. The majority of the samples achieved an internal run precision of better than ± 0.00001 (2σ). For the analysis of strontium ratios by TIMS, results need to undergo a subsequent mathematical correction to eliminate measurement errors. The internal standard has gone through the same chemical preparation steps as the samples and thus highlights errors within the chemical collection of the samples; an external standard is used to detect errors occurring during the measurement procedure. Strontium ratios were corrected to an accepted value for the NIST SRM 987-standard of 0.710248 (Thirlwall, 1991; but cf. Avanzinelli et al., 2005 with a NIST SRM 987 of 0.710251 ± 11).

4.3.3.2 Methodology for comparative samples

Dentine was analysed in the absence of further comparative samples and in addition to the available baseline samples. A vertical chunk of primary dentine was selected for analysis. After removing all adhering tooth enamel, dentine was analysed following the same procedure as for enamel. Possible residues after centrifugation were excluded from analysis. Pre-treatment procedures such as acid leaching to remove integral diagenetic phases or chemical contamination from the samples were dismissed. Human bone was sampled from some sites, though in most cases no bone material was available for analysis. A piece of approximately 30 mg of compact bone was selected and mechanically cleaned. The following procedure is equivalent to the one for tooth enamel with the exception that after centrifu-

gation, possible residues were excluded from analysis. No pre-treatment with acids was applied due to the fact that bone should reflect the burial environment instead of the individual's last years of life.

Complete teeth of rodents and tooth enamel from larger mammals were selected for analysis. Molluscs were cleaned mechanically and dissolved as a whole. Their analysis also followed the procedure described for human tooth enamel samples.

Approximately 2 g of plant material, i.e. leaves and grasses, were selected for analysis. The plant material was if possible collected from uncultivated areas a good distance from human impact, though cultivated fields could not always be avoided. The selected material was first thoroughly washed with Milli-Q water, dried under cover in an oven at 40 °C for several hours and finally hand-crushed. Around 0.5 g of the dried and crushed material was placed into clean Teflon beakers and transferred to the clean laboratory in the Department of Earth Sciences, University of Bristol. There, it was dissolved in 3 ml 16 N HNO_3 for at least 24 hours. The time taken for successful complete dissolution varied. 2 ml of the solution was pipetted off and dried down on a hot plate. It was then treated following the procedure for tooth enamel described above.

Each soil sample weighed 4 g, of which 2 g were leached in 5 ml Milli-Q ultra-pure water and the other 2 g in 5 ml 10% vol. acetic acid to extract soluble and exchangeable ions for 24 hours. Samples were ultrasonicated for 3 hours and afterwards centrifuged on 4000 rotation for 20 minutes. 3 ml of the leachate was pipetted out and dried down on a hot plate. The sample procedure then followed the one described above.

4.3.3.3 Strontium concentration measurements

All tooth enamel and dentine samples were selected for additional Sr concentration measurements. Samples were prepared and digested as for $^{87}Sr/^{86}Sr$ analysis. The sample preparation followed the method for $^{87}Sr/^{86}Sr$ analysis as outlined in Table 4.2 until step II.6. Samples were then further diluted in two steps: 20 µl of the sample stock solution was diluted into 1980 µl 2% HNO_3, then 1 µl of this solution was diluted into 1949 µl of 2% HNO_3 and 50 µl of the spike solution was added. Sequences of 21 samples in solution and three standards equalling 10 ppb, 1 ppb and 0.1 ppb were analysed on a Finnigan Element 2 high-resolution, single collector, fast scanning magnetic-sector inductively-coupled mass spectrometer at the University of Bristol, Department of Earth Sciences. The analysed masses are reported in ppb. Calcium interferences cannot be excluded since the samples were separated before the column procedure, due to the late decision to test for Sr concentration.

4.3.4 Results

The results of the $^{87}Sr/^{86}Sr$ analysis are shown in Appendix A. The presentation and discussion of the results in this chapter follows chronological periods and geographical location. Negligible error bars and sample labels are not included in the figures to avoid overloading with information.

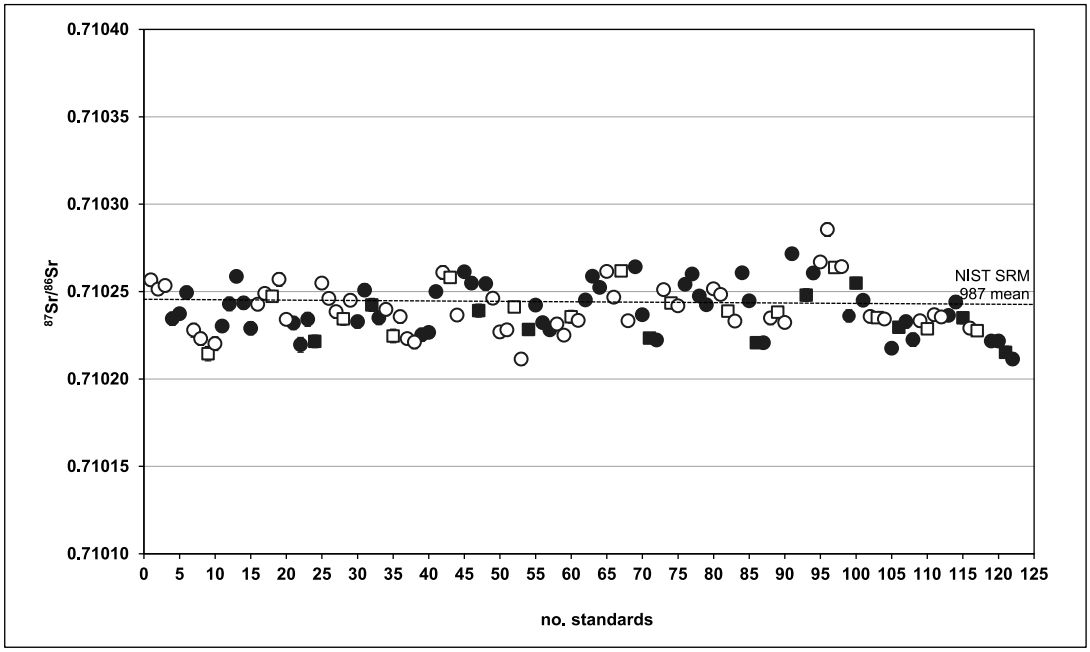


Fig. 4.5 | $^{87}Sr/^{86}Sr$ values for external standard NIST SRM 987 of sequences 1 to 32 including standard errors (1σ). Sequences are differentiated by white or blue colour, circles signify standard measurements, and diamonds symbolize the combinations of standards and blanks. 32 sequences and 120 standard analyses yielded a mean value of 0.710240 ± 0.00001 (1σ) or 0.00003 (2σ). The line marks the accepted Sr mean ratio of 0.710248 for NIST SRM 987. The mean deviation was 0.000010.

4.3.4.1 Correction of the $^{87}Sr/^{86}Sr$ isotope ratios

The NIST SRM 987 serves routinely as an external standard for strontium isotope procedure in the Bristol Isotope Group. The standard is added three to four times to each sequence of 15 to 16 samples and one internal standard. Over 32 sequences, 122 standards of NIST SRM 987 were analysed. To achieve a higher sensitivity, the initial sample amount of 596 µg was lowered to 199 µg after sequence 21. One of the standards in sequences 24 and 31 yielded not only a diverged value but also a high standard error and was therefore excluded in the computation of the mean standard value for $^{87}Sr/^{86}Sr$. The repeated $^{87}Sr/^{86}Sr$ measurement of the standard NIST SRM 987 resulted in a mean of 0.710240 ± 0.000014 (1σ, n = 120) (Fig. 4.5). To remove any instrumental error in the measurement of each sequence, the mean of the sequence's standards was calculated and adjusted to the accepted NIST SRM 987 value of 0.710248 (Thirlwall, 1991).

A cattle tooth (WH 9.4) from the prehistoric site at Windmill Hill, United Kingdom, served as an internal standard. Cattle tooth enamel offers higher concentrations and more stable strontium ratios than human tooth enamel, and this qualifies it as a standard. The cattle tooth enamel sample WH 9.4 was included in each of the 30 first sequences of 21 samples. In two sequences (sequences 10, 27) no internal standard was included on account of failures during chemistry procedures. In sequence 13, the analysis of WH 9.4 failed. The mean value of WH 9.4 after 27 valid sequences was 0.708613 ± 0.000014 (1σ, n = 27). After correction of the $^{87}Sr/^{86}Sr$ ratios to the internationally acknowledged value of 0.710248 (Thirlwall, 1991), the mean value was increased to 0.708619 ± 0.000010 (1σ) (Fig. 4.6).

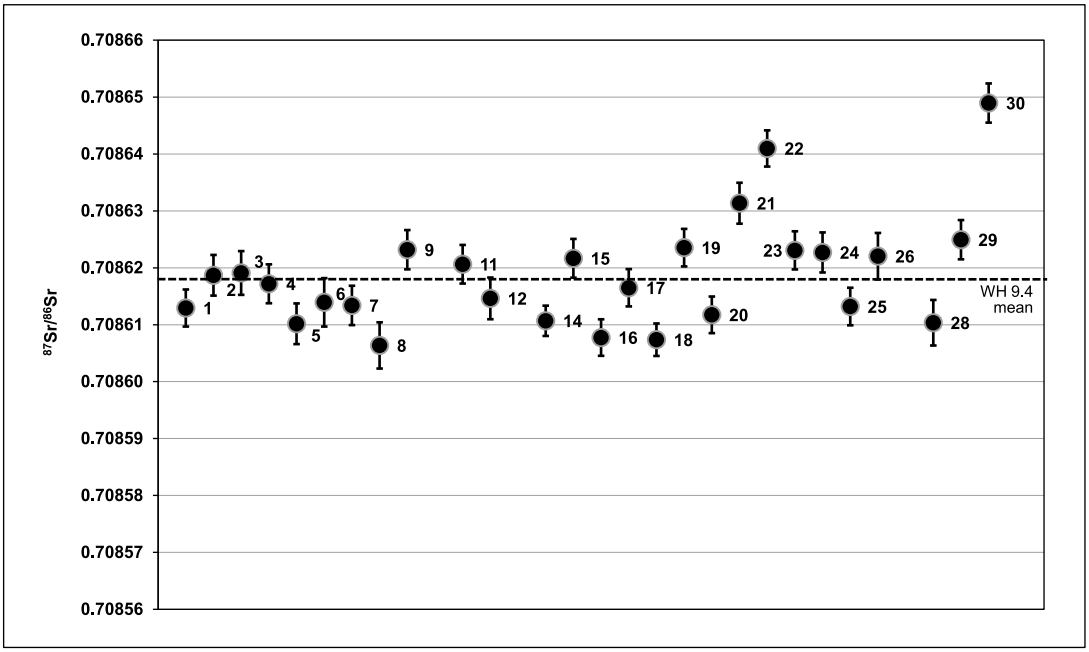


Fig. 4.6 | Corrected internal standard WH 9.4 of sequences 1 to 30 including standard errors (1σ). They yielded a mean value of 0.708619 ± 0.00001 (1σ) or 0.00003 (2σ).

4.3.4.2 Results of the $^{87}Sr/^{86}Sr$ analysis

4.3.4.2.1 Eneolithic and Bronze Age

Bulgaria

36 teeth from 27 human individuals were sampled from four Bulgarian sites (Fig. 4.7). The mean $^{87}Sr/^{86}Sr$ values for the Bulgarian samples as a whole is 0.70857 ± 0.00082 (1σ), and most of the samples fall within the limits of 0.708 and 0.7095.

A very limited range is given for Benkovski. Eight individuals fall within the limits of 0.70805 and 0.70829. The average strontium ratio for this site is 0.70832 ± 0.00044 (1σ). Both individuals that were sampled in duplicates yielded very similar values in both their teeth, which leads to the assumption that, for the period of mineralisation of those teeth, the individuals were living on similar geologies with a likelihood therefore that they stayed within a geologically prescribed area. One individual yielded a comparatively radiogenic result (0.70926) and can be considered an outlier, showing a similar strontium ratio to the mean of the Boyanovo and Ovchartsi samples. The mean Sr ratio of the five individuals from Boyanovo is 0.70867 ± 0.00069 (1σ) with a range of 0.70771 to 0.70939. Two humans from Boyanovo were sampled in duplicate and these gave results with a difference of more than 0.0015 per individual. This large variation suggests a change in nutrition, in mobility behaviour and/or the place where they lived during the years of tooth enamel mineralization. Two of the samples, the first molar of the individual in grave 4 and the third molar of individual 1 in grave 14, might be considered as outliers, because they resulted in a significantly lower $^{87}Sr/^{86}Sr$ value than the four remaining samples that are all within the limits of 0.70867 to 0.7093. Interestingly, the two outliers yield very similar $^{87}Sr/^{86}Sr$ values, sug-

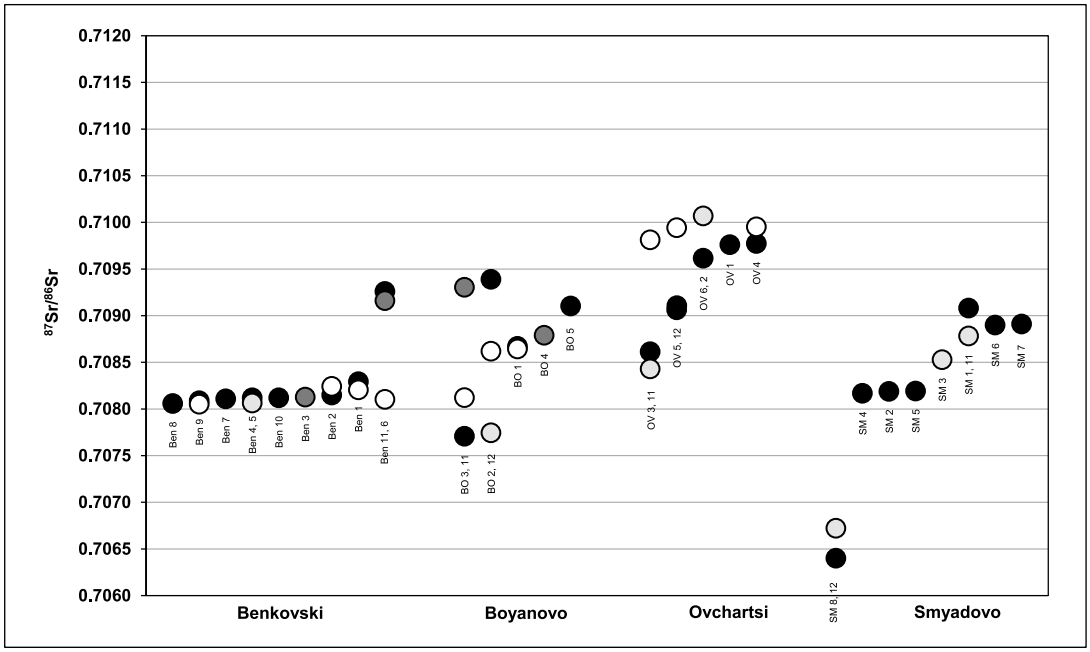


Fig. 4.7 | $^{87}Sr/^{86}Sr$ data for the four Bulgarian sites. First molars (black circles), second molars (light grey circles), third molars (dark grey circles), dentine (white circles). If the individuals were analysed for a second tooth, symbols are arranged in a line.

gesting that the places they moved to/from had a similar geology. The five individuals sampled from Ovchartsi yielded $^{87}Sr/^{86}Sr$ ratios between 0.70843 and 0.71007 with a mean value of 0.70935 ± 0.00057 (1σ). The most radiogenic value not only for the site but also for all Bulgarian samples is given by the third molar of the deceased in 'The Big Barrow' grave 9. The results for the three individuals that were sampled in duplicate ['The Big Barrow' graves 1 (two first molars?), 9 and 15 (first and third molars)] are very similar and this suggests a restricted mobility within different geological regions during infancy. The $^{87}Sr/^{86}Sr$ ratios for the eight sampled individuals from Smyadovo resulted in an average of 0.708024 ± 0.00103 (1σ) with the lowest value at 0.7064 and the highest value at 0.70908. Grave 6 is an outlier giving two similar, but very low $^{87}Sr/^{86}Sr$ ratios.

Hungary

20 individuals from nine sites in the East Hungarian Plain including the sites Sárrétudvari-Örhalom and Kétegyháza-Kétegyházi tanyák were selected for strontium isotope analysis (Fig. 4.8). The samples from Sárrétudvari-Örhalom yielded Sr ratios between 0.70996 and 0.71157 with a mean of 0.71063 ± 0.00049 (1σ). The individuals analysed in duplicate yielded very consistent results that suggest no major changes in nutrition or residence. Despite the fact that the geology of the plain is somewhat homogeneous, Kétegyháza-Kétegyházy tanyák had a much lower mean of 0.70936 ± 0.00034 (1σ) with $^{87}Sr/^{86}Sr$ ratios ranging between 0.70917 and 0.70987. A possible outlier from grave 3 in kurgan 6 is consistent with results from other sites on the Eastern Hungarian Plain. The $^{87}Sr/^{86}Sr$ ratios for the sites excluding Kétegyháza-Kétegyházy tanyák yielded a mean of 0.70985 ± 0.00026 (1σ) with a range of 0.7095 to 0.71012. Despite the rather wide range in strontium ratios, the samples are discussed as one entity due to the homogenous nature of the geology of the East Hungarian Plain. In summary, the 20 samples yield

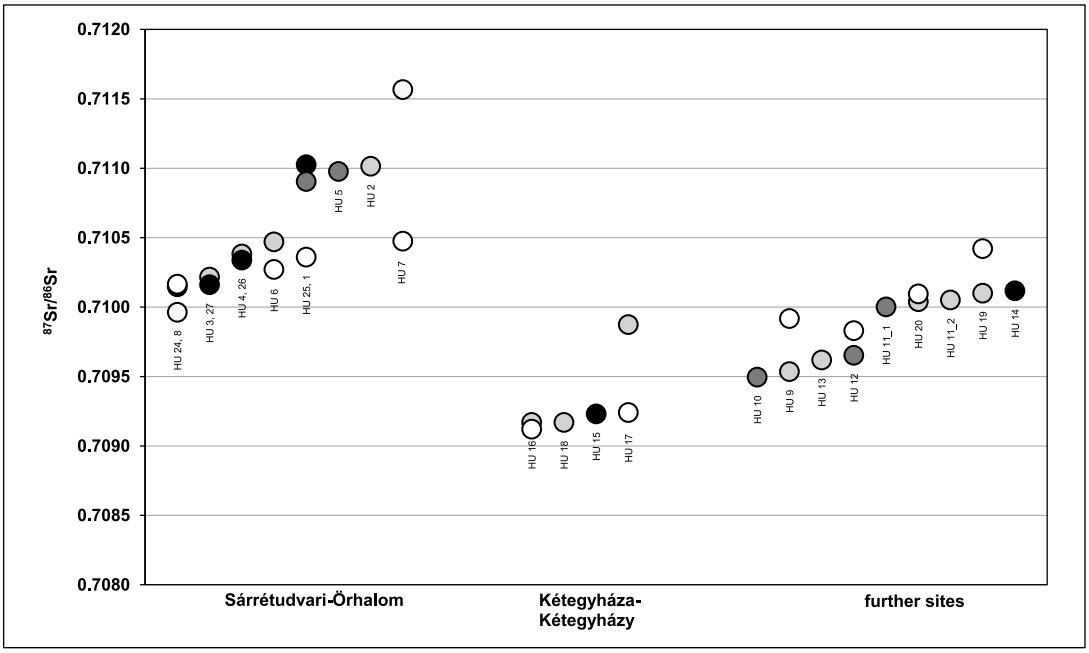


Fig. 4.8 | $^{87}Sr/^{86}Sr$ data for sites on the East Hungarian Plain: First molars (black circles), second molars (light grey circles), third molars (dark grey circles), second premolars (very light grey), dentine (white circles). If the individuals were analysed for a second tooth symbols are arranged in a line.

a relatively high average of 0.71013 ± 0.00062 (1σ), which is caused by the six high values from Sárrétudvari. The values from Kétegyháza, on the other hand, lie at the lower end of the range.

North Pontic region

40 individuals from five sites in the North Pontic region were sampled for Sr isotope analysis (Fig. 4.9). 25 of these individuals were analysed in duplicate. Due to geological variations between the sites, a comparison of the North Pontic sites as a whole is problematical. Results from five individuals from Nevskoe fell within a very narrow $^{87}Sr/^{86}Sr$ ratio range of 0.70905 to 0.70924, with a mean value of 0.70915 ± 0.00008 (1σ). Very narrow $^{87}Sr/^{86}Sr$ ranges are also given for the sites Shakhta Stepnaya and Vinogradnoe. Peshtchanka and Kirovograd (Sugokleya), however, show a broader range in their $^{87}Sr/^{86}Sr$ values. Similar $^{87}Sr/^{86}Sr$ values for the four individuals from Shakhta Stepnaya had an average of 0.70995 ± 0.00008 (1σ) and ranged between 0.70978 and 0.71003. Three individuals sampled in duplicate show extremely small differences. Results for the 16 individuals analysed from Vinogradnoe are also very similar with a range between 0.7095 and 0.71023 and a mean of 0.70982 ± 0.00017 (1σ). The nine humans, which were analysed in duplicate, showed only small variations between their first and second teeth sampled. In Peshtchanka seven individuals were sampled, all of them in duplicate, resulting in a $^{87}Sr/^{86}Sr$ ratio range between 0.70956 and 0.71082 and a mean $^{87}Sr/^{86}Sr$ ratio of 0.71029 ± 0.00033 (1σ). The variation between the two analysed teeth is consistently small. The only site where larger variations, not only in general but also between two teeth of single individuals, were detected is Kirovograd. Significant differences can be seen in half of the sampled humans. The rather large variation in $^{87}Sr/^{86}Sr$ ratios in general has a minimum value of 0.70953 and a maximum of 0.71205. The mean value of 0.71068 ± 0.00062 (1σ) is the highest of the North Pontic area.

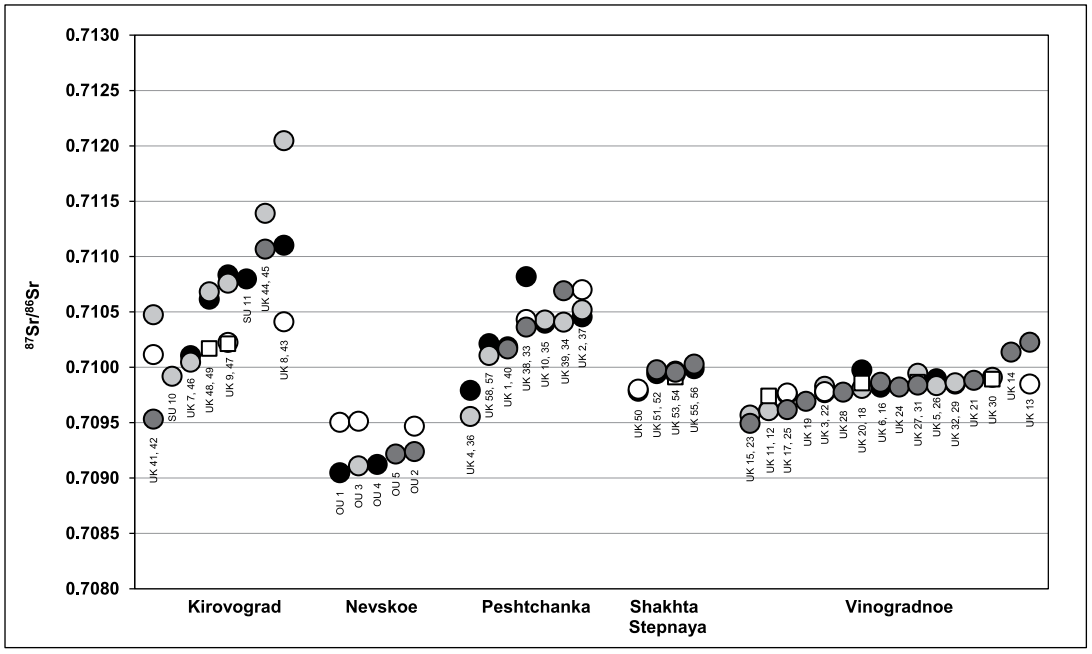


Fig. 4.9 | $^{87}Sr/^{86}Sr$ data for sites in the North Pontic area: First molars (black circles), second molars (light grey circles), third molars (dark grey circles), dentine (white circles), bone (white squares). If the individuals were analysed for a second tooth symbols are arranged in a line.

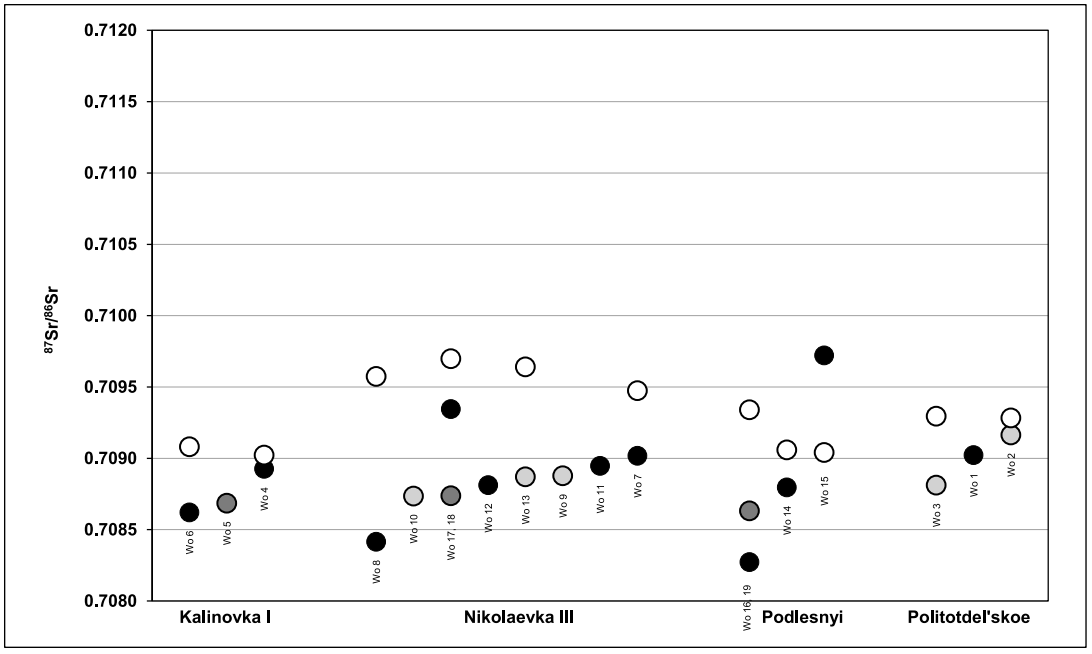


Fig. 4.10 | $^{87}Sr/^{86}Sr$ data for sites in the Middle Volga region: First molars (black circles), second molars (light grey circles), third molars (dark grey circles), dentine (white circles). If the individuals were analysed for a second tooth symbols are arranged in a line.

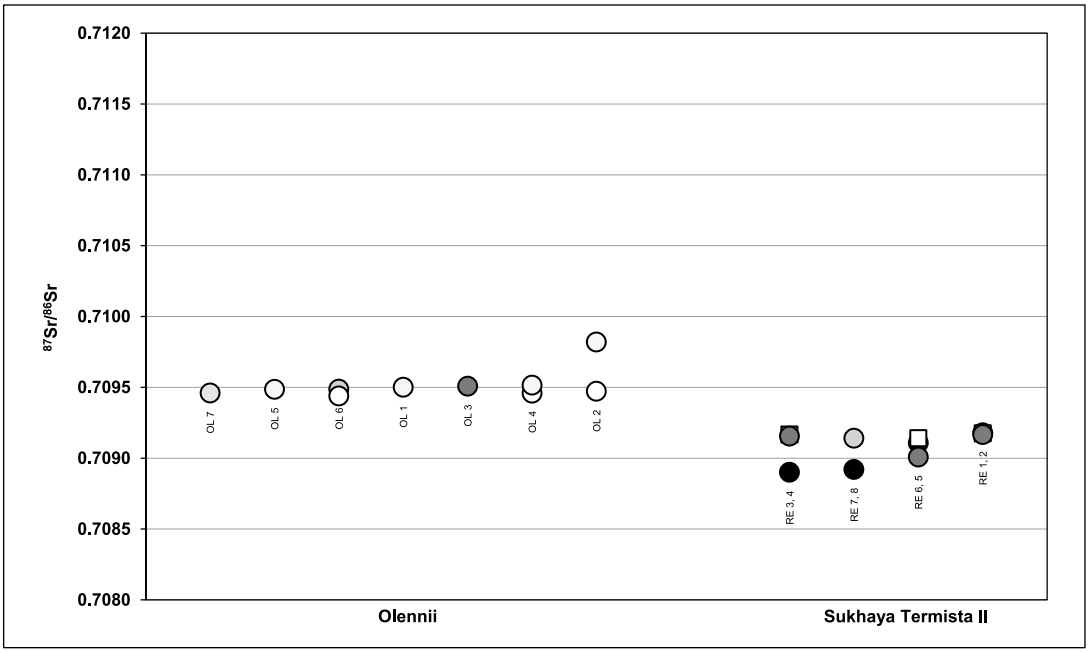


Fig. 4.11 | $^{87}Sr/^{86}Sr$ data for Olennii (Kuban region) and Sukhaya Termista II (Southern Russia): First molars (black circles), second molars (light grey circles), third molars (dark grey circles), deciduous molars and canines (very light grey circles), dentine (white circles), bone (white squares). If the individuals were analysed for a second tooth symbols are arranged in a line.

Volga region

In the Volga region, 17 individuals were analysed from four sites (Fig. 4.10). The average $^{87}Sr/^{86}Sr$ ratio for the whole Volga region is 0.70888. Despite the differences in geologies, the $^{87}Sr/^{86}Sr$ ratios are similar across all the sites. The average $^{87}Sr/^{86}Sr$ ratio from the three individuals from Kalinovka I is 0.70874 ± 0.00016 (1σ) ranging between 0.70862 and 0.70893. Nikolaevka III has a marginally more radiogenic mean of 0.70886 ± 0.00025 (1σ) and a range between 0.70842 and 0.70935. One individual (kurgan 2 grave 1 individual 2) was sampled in duplicate and showed a significant difference between the two teeth. Podlesnyi yields an average $^{87}Sr/^{86}Sr$ ratio of 0.70886 ± 0.00062 (1σ), though the three individuals present heterogeneous results. Another three individuals were selected for strontium isotope analysis from Politotdel'skoe. The results range between 0.70881 and 0.70916 with a mean of 0.70900 ± 0.00018 (1σ). Small sample sizes make the objective interpretation of the $^{87}Sr/^{86}Sr$ data from the Middle Volga region challenging.

South Russia

At Sukhaya Termista II in the southern Russian steppes $^{87}Sr/^{86}Sr$ ratios are very similar (Fig. 4.11). The two results for each of the four individuals yield an average value of 0.70907 ± 0.00011 (1σ) with a range of 0.7089 to 0.70918 and little or no variation between first and second teeth sampled.

The $^{87}Sr/^{86}Sr$ ratios for the seven individuals from Olennii in the Kuban region are also extremely consistent. They range between 0.70946 and 0.70982, with a mean of 0.70954 ± 0.00013 (1σ). Six of the seven individuals have almost identical ratios.

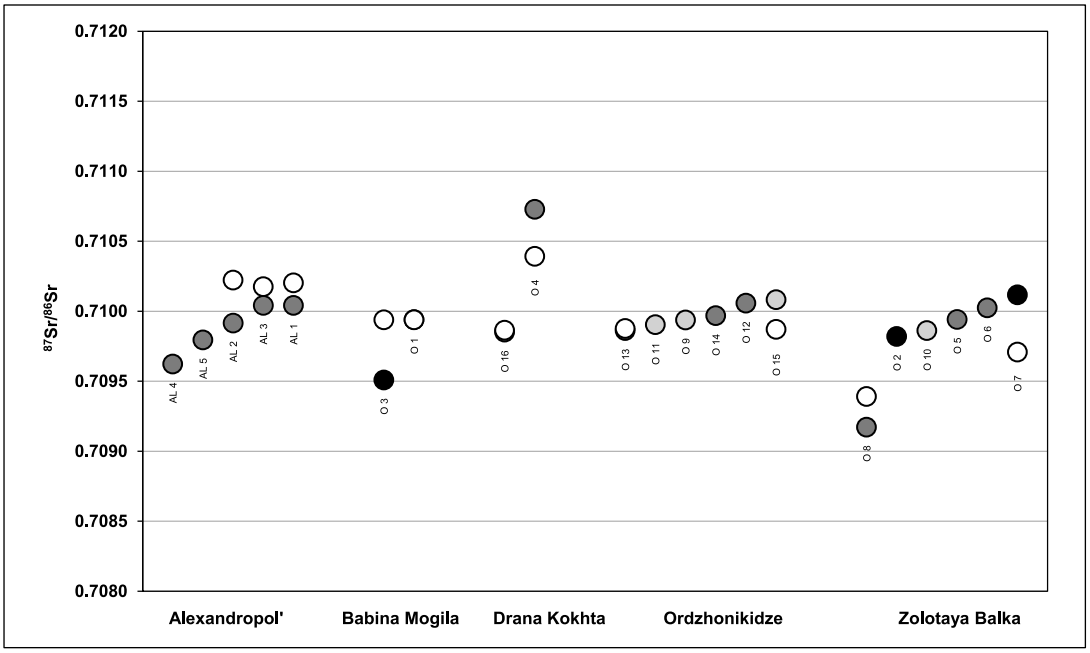


Fig. 4.12 | $^{87}Sr/^{86}Sr$ data for the Scythian samples from the five North Pontic sites: First molars (black circles), second molars (light grey circles), third molars (dark grey circles), deciduous molars and canines (very light grey circles), dentine (white circles).

4.3.4.2.2 Iron Age

North Pontic region

21 individuals were sampled from five sites in the North Pontic region and gave similar results (Fig. 4.12). with a mean of 0.70991 ± 0.00029 (1σ) and few outliers. The five individuals from Alexandropol' had a mean value of 0.70988 ± 0.00018 (1σ) with a range between 0.70962 and 0.71004. Two individuals were sampled from each of the sites of Babina Mogila and Drana Kokhta, and yielded diverse results. The mean of the first site is 0.70972 ± 0.00031 (1σ), and of the latter is 0.71029 ± 0.00062 (1σ). This is the highest mean value of the North Pontic and is explained by the high value from one of the humans. The very consistent values from Ordzhonikidze had a mean of 0.70997 ± 0.00009 (1σ) with a range between 0.70986 and 0.71008. The same uniformity can be seen in Zolotaya Balka, where the six human samples had a mean of 0.70982 ± 0.00034 (1σ). While the outlier causes an unexpectedly low minimum range value of 0.70917, the maximum (0.71012) is similar to the other values for the North Pontic.

Berel' (Kazakhstan)

Six humans and five horses were sampled from the site of Berel' (Fig. 4.13). Two individuals were sampled in duplicate: kurgan 10 (PM1, M1) and kurgan 32 (two M3). The mean of all 18 human and horse $^{87}Sr/^{86}Sr$ ratios is 0.71148 ± 0.00064 (1σ), and while the mean value for the humans is 0.71125 ± 0.00034 (1σ), the one for the horses is 0.71161 ± 0.00074 (1σ). The human $^{87}Sr/^{86}Sr$ ratios are rather variable, with the lowest value of 0.71075 and the highest value of 0.71167. The results for the horses show an even more scattered picture with the minimum value at 0.71061 and the maximum at 0.71264.

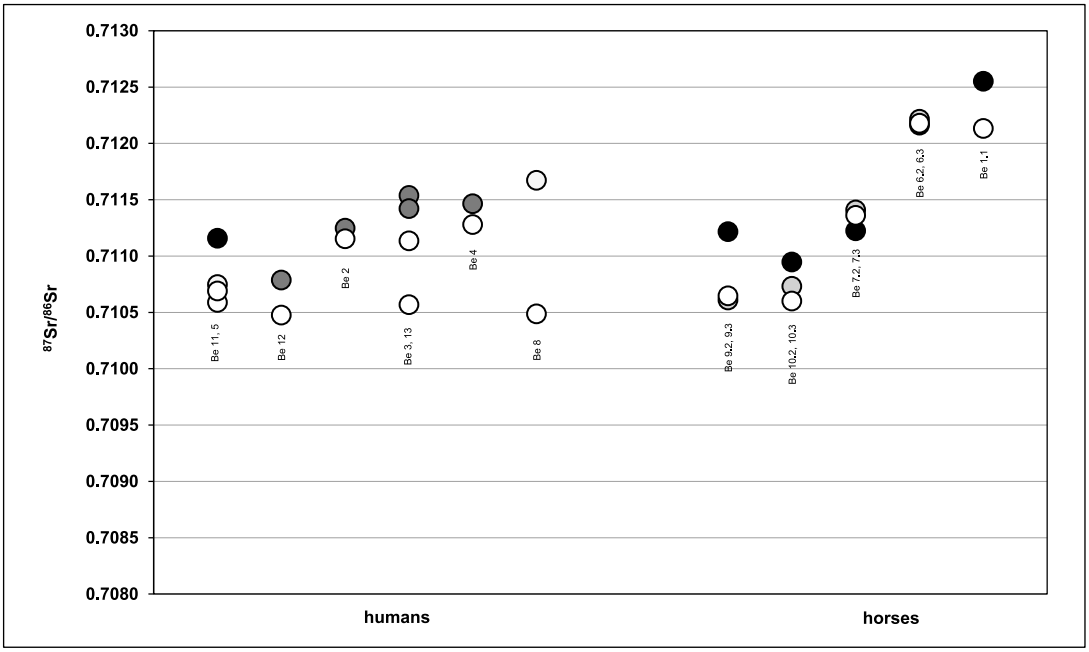


Fig. 4.13 | $^{87}Sr/^{86}Sr$ data for Berel'. Humans: First molars (black circles), second molars (light grey circles), third molars (dark grey circles), first premolars and an incisors (very light grey circles), dentine (white circles). If the individuals were analysed for a second tooth, symbols are arranged in a line.
Horses: Each horse tooth was sampled twice. The cusp is symbolized by black circles, the cervix is symbolized by grey circles, the dentine is symbolized by white circles.

While there is almost no variation between the teeth sampled in duplicate for most of the individuals, one of the humans (kurgan 10) and one of the horses (kurgan 23) show a larger variation between the first and second sampled teeth.

4.3.4.3 Intra-site and inter-site comparison

The sites are compared on an intra-site and regionally on an inter-site level (Fig. 4.14). The four Bulgarian sites (Ben, Bo, Ov, Sm) show similar $^{87}Sr/^{86}Sr$ ranges but different distributions with means between 0.708 and 0.710. The range of Benkovski is extremely narrow and the outliers are still within the ranges of the other Bulgarian sites. The two outliers of Smyadovo, however, are far lower. The Hungarian samples (HU) are more clearly offset, with a more radiogenic mean. The North Pontic $^{87}Sr/^{86}Sr$ ranges are comparatively more radiogenic than these regions. There are obvious variations in the width of the ranges with a very widespread distribution in Kirovograd and very narrow ranges in Nevskoe, Shakhta Stepnaya and Vinogradnoe. The width of the ranges correlates with the geological variety in the surrounding region rather than with sample sizes. The Russian sites yield very narrow $^{87}Sr/^{86}Sr$ ranges, and this is most extreme in Olennii. Podlesnyi, however, shows a wide spread of values, even though only three individuals were sampled.

The Scythian samples from Berel' yield very radiogenic $^{87}Sr/^{86}Sr$ ratios, which are characteristic of mountainous regions. The comparably high $^{87}Sr/^{86}Sr$ ratios of some of the Hungarian samples also sug-

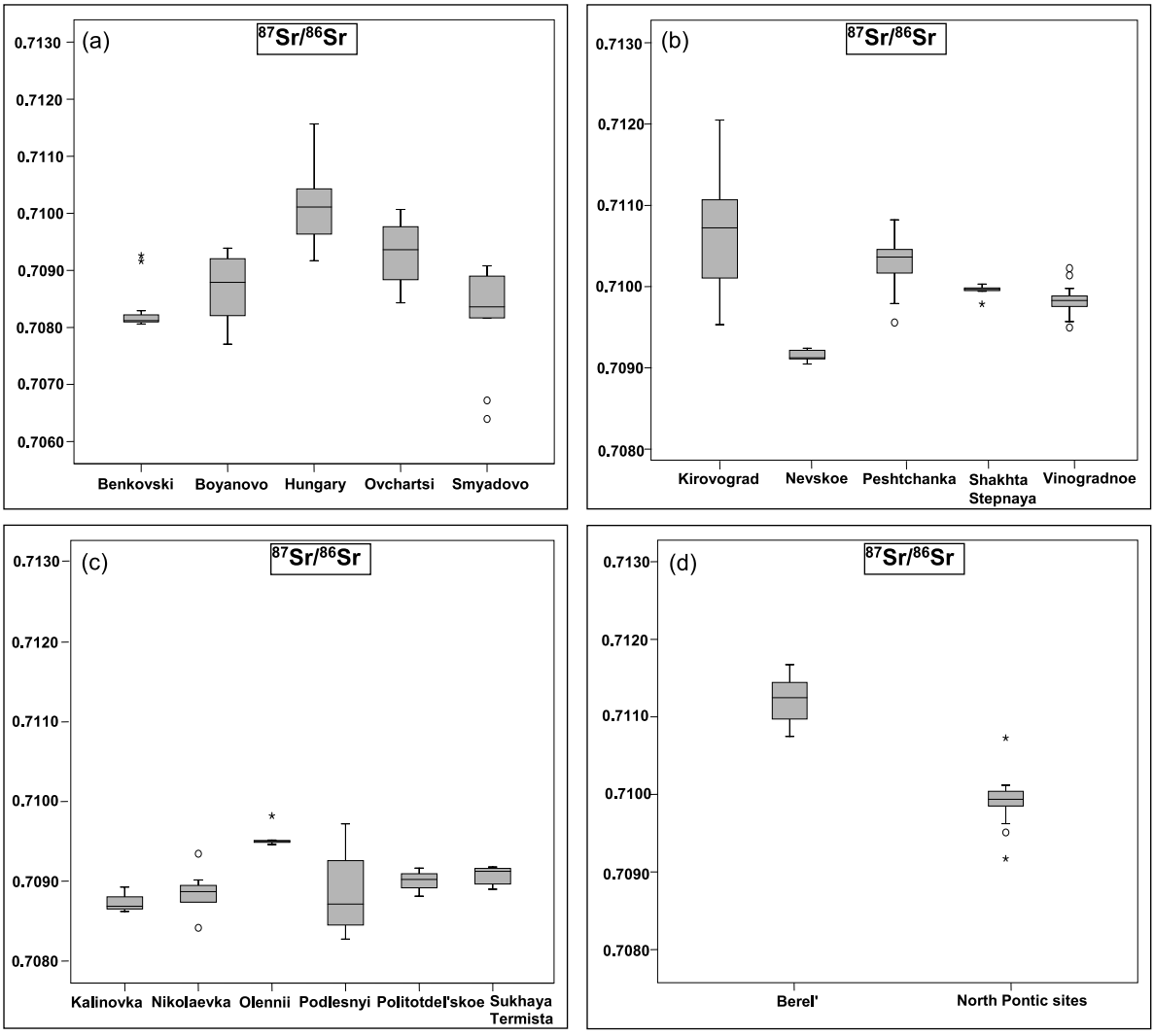


Fig. 4.14 | Box plots of the $^{87}Sr/^{86}Sr$ ranges for the Eneolithic and Bronze Age sites in the Carpathian-Balkan region (a), the North Pontic region (b), and Russia (c). Iron Age sites (d) are also shown.

gest a connection to the mountains. Results from the North Pontic individuals are clustered closely within the range of a rather homogeneous geology with some outliers.

Statistically, the sites vary from each other. A Kolmogorov-Smirnov test showed that the $^{87}Sr/^{86}Sr$ values are normally distributed ($Z = 1.08$, $p = 0.2$). A Levene test showed that there was no homogeneity of variances ($F = 4.33$, $p < 0.001$). Therefore, a one-way ANOVA was performed, which showed that there are highly significant differences between the sites ($F = 31.43$, $p < 0.001$) and additionally a Kruskal-Wallis test, which confirmed the results of the one-way ANOVA ($x^2 = 148.65$, $p < 0.001$).

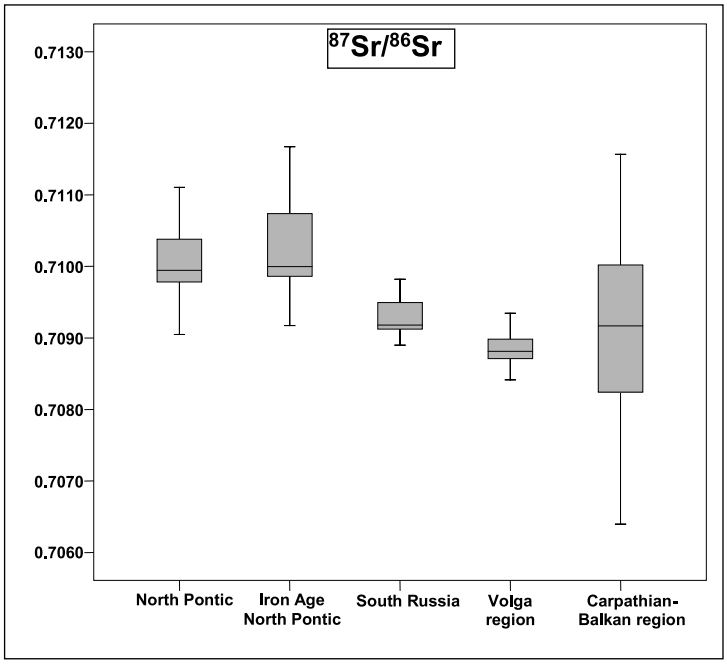


Fig. 4.15 | Box plots of the $^{87}Sr/^{86}Sr$ ranges on a regional scale for the Eneolithic and Bronze Age and Iron Age sites in the North Pontic, the Eneolithic and Bronze Age sites in the Volga resgion, South Russia and the Carpathian-Balkan region.

4.3.4.4 Inter-regional comparison

When compared at a regional level (Fig. 4.15), it is apparent that the Carpathian-Balkan samples have the widest range, due to the low radiogenic outlier in Smyadovo and the very radiogenic samples in Sárrétudvari. By comparison, the North Pontic samples are less widely distributed, even though they are as numerous as the Carpathian-Balkan ones. This difference may be explained by the greater variation in the geology of the Carpathian-Balkan region. On the basis of a negative Levene test ($F = 4.98$, $p = 0.001$) a one-way ANOVA was performed, which showed significant differences between the regions ($F = 50.85$, $p > 0.001$) and in additon a Kruskal-Wallis test, which supported the results ($x^2 = 101.7$, $p < 0.001$). A Tukey's HSD post hoc test revealed that no significant differences exist between Bulgaria and the Volga region, Hungary and the North Pontic, the Volga region and South Russia, and the North Pontic Eneolithic/Bronze Age and Scythian samples.

4.3.4.5 Differences related to gender and age

4.3.4.5.1 Eneolithic and Bronze Age

The box plots (Fig. 4.16) and Appendix B Table 1 present the mean and median $^{87}Sr/^{86}Sr$ values including standard deviations for males, females and skeletons of undetermined sex. For the Carpathian-Balkan region only the summarized Hungarian sites (HU) offer a basis for comparison, but no significant differences between the sex groups exist.

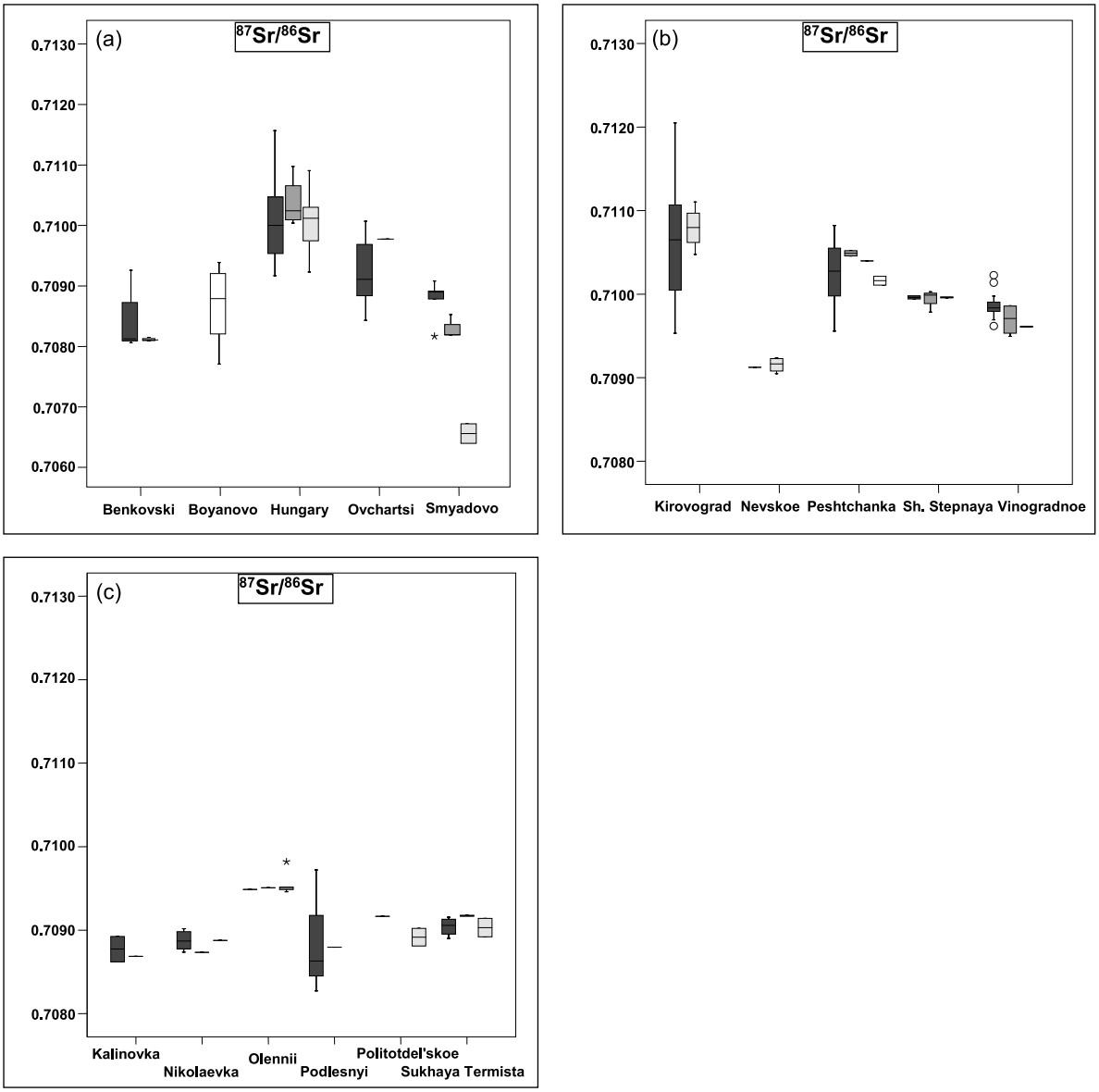


Fig. 4.16 | $^{87}Sr/^{86}Sr$ ranges based on sex-related differences (male = black, female = dark grey, ? = light grey, undetermined = white) for the Eneolithic and Bronze Age sites in the Carpathian-Balkan region (a), the North Pontic region (b) and Russia (c).

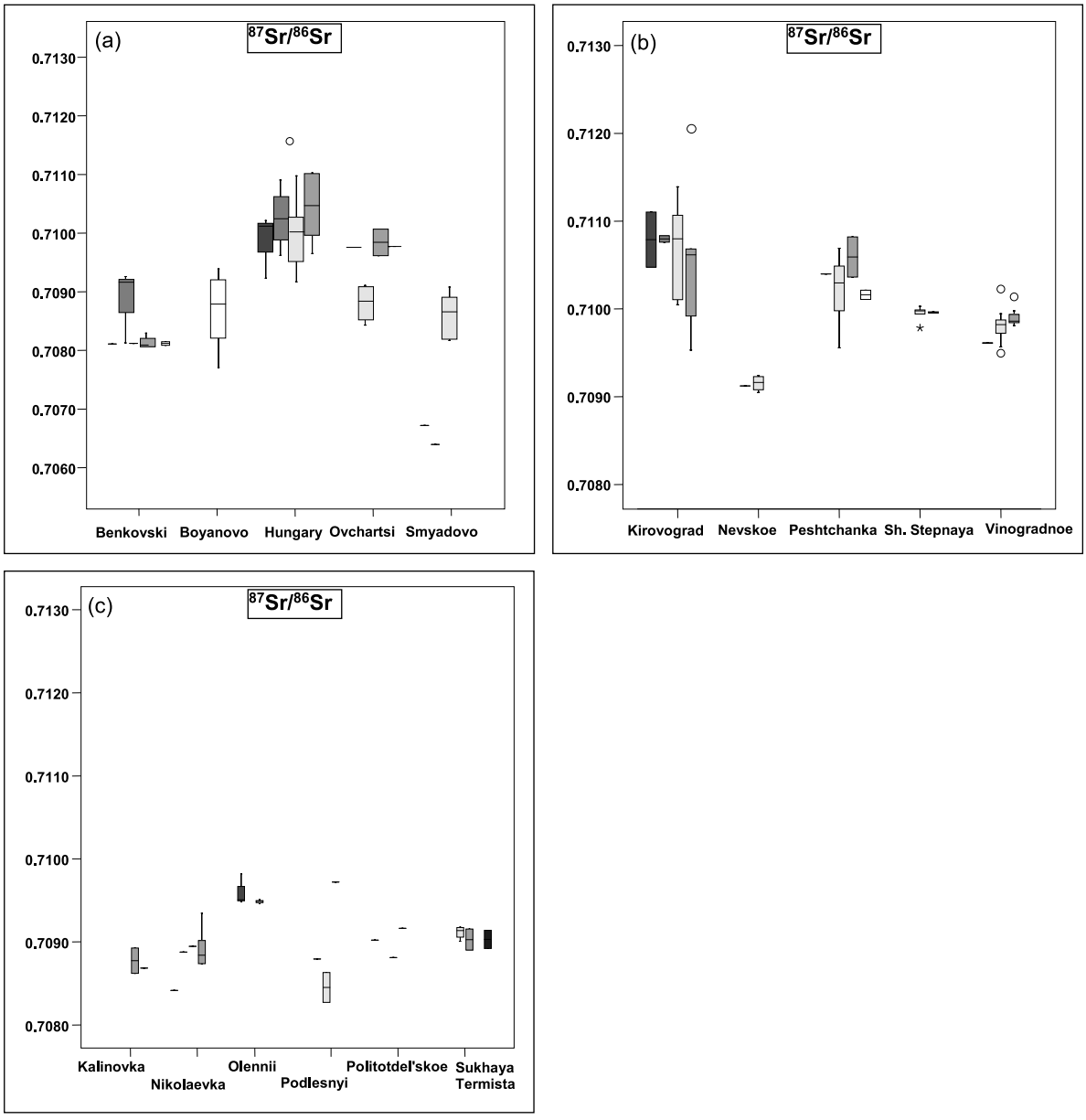


Fig. 4.17 | $^{87}Sr/^{86}Sr$ ranges based on age-related differences (infant = light black, juvenile = dark grey, adult = light grey, mature = medium grey, ? = black, undetermined = white) for the Eneolithic and Bronze Age sites in the Carpathian-Balkan region (a), the North Pontic region (b) and Russia (c).

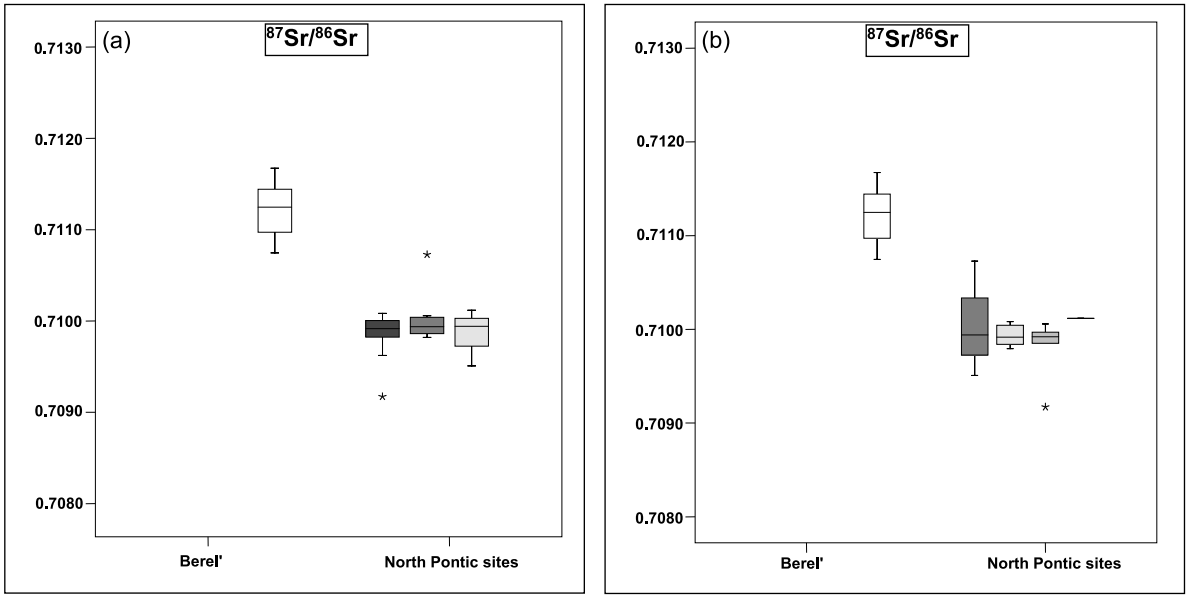


Fig. 4.18 | $^{87}Sr/^{86}Sr$ ranges based on (a) sex-related differences (male = black, female = dark grey, ? = light grey, undetermined = white) and (b) on age-related differences (infant = light black, juvenile = dark grey, adult = light grey, mature = medium grey, ? = black, undetermined = white) for the Iron Age sites.

No significant differences can be determined between the age groups of the Carpathian-Balkan sites either despite the samples of the mature individuals at Ovchartsi being more radiogenic than the adult ones. There are no sex-related differences at the North Pontic nor at the Russian sites (Fig. 4.17).

4.3.4.5.2 Iron Age

The box plot diagrams (Fig. 4.18) show the means of the non-sex-determined skeletons from Berel' and the male and female individuals as well as the skeletons of unknown sex from the North Pontic and the different age groups from the same areas. No significant differences can be found for any of the criteria.

4.3.4.5.3 Comparison on a regional scale

On a regional scale (Fig. 4.19), comparison shows no significant difference between the sexes in the Volga and North Pontic regions during the Eneolithic and the Bronze Age, nor in the Scythian period. The high radiogenic values of the Scythian period and the variations at the South Russian sites are site-related. In the Carpathian-Balkan region alone, there appears to be a distinction between male individuals, which tend to have lower $^{87}Sr/^{86}Sr$ ratios and the more radiogenic values for females and undetermined skeletons. Statistically, these differences are not significant (North Pontic: $F = 0.21$, $p = 0.81$; one-way ANOVA, confirmed by a Kruskal-Wallis test: $x^2 = 0.35$, $p = 0.84$; West Pontic: $F = 1.63$, $p = 0.21$; one-way ANOVA, based on a positive Levene test; Russia: $F = 2.96$, $p = 0.07$; one-way ANOVA, based on a positive Levene test).

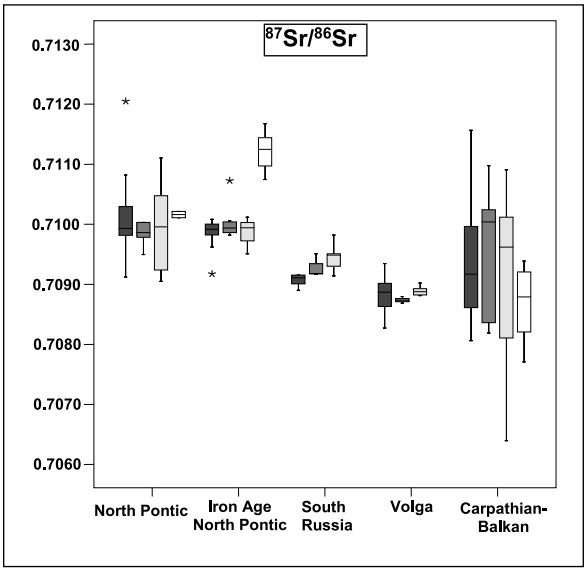


Fig. 4.19 | $^{87}Sr/^{86}Sr$ ranges based on sex-related differences on a regional scale (male = black, female = dark grey, ? = light grey, undetermined = white).

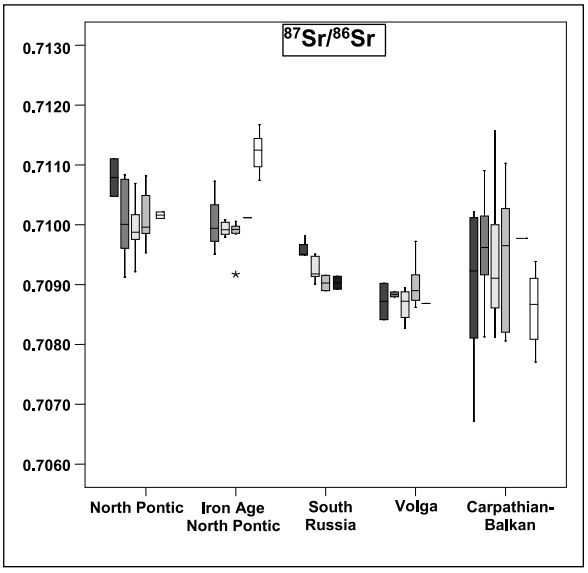


Fig. 4.20 | $^{87}Sr/^{86}Sr$ ranges based on age-related differences on a regional scale (infant = light black, juvenile = dark grey, adult = light grey, mature = medium grey, ? = black, undetermined = white).

No age-related variations can be seen on a regional scale in the Volga region, the Carpathian-Balkan region or the North Pontic region for the Scythian period (Fig. 4.20, Appendix B Table 2). There are no statistical differences according to age groups in the Carpathian-Balkan region ($F = 1.46$, $p = 0.23$; one-way ANOVA, based on a positive Levene test) and Russia ($F = 0.88$, $p = 0.49$; one-way ANOVA, based on a positive Levene test). Statistically relevant differences related to age were observed for the North Pontic region ($F = 7.00$, $p < 0.001$; one-way ANOVA, based on a positive Levene test). Differences (Tukey HSD) exist between infants and the other age groups, namely the juvenile ($p = 0.002$), adult ($p < 0.001$) and mature individuals ($p = 0.001$).

4.3.4.6 Chronological differences

Chronological differences in $^{87}Sr/^{86}Sr$ ratios are difficult to detect due to the small sample sizes per cultural group (Fig. 4.21, Appendix B Table 3). No major variations exist in Boyanovo and the Hungarian sites, the only sites in the Carpathian-Balkan region where different chronological groups were sampled. In the North Pontic region, sampled individuals were mainly from the Eneolithic, Yamnaya and the subsequent Catacomb cultures. The Eneolithic samples in Vinogradnoe show a slightly more elevated mean, the samples of the Catacomb culture are marginally decreased in $^{87}Sr/^{86}Sr$. In Kirovograd, Yamnaya skeletons resulted in a wider $^{87}Sr/^{86}Sr$ range than individuals from the Catacomb culture. No general trends can be observed for the Russian sample sites.

Summarized on a regional scale, the Carpathian-Balkan samples of the Early Bronze Age have enriched $^{87}Sr/^{86}Sr$ ratios compared to the Eneolithic and the Middle Bronze Age samples and the North Pontic skeletons belonging to the Catacomb culture have less radiogenic $^{87}Sr/^{86}Sr$ ratios than the Eneo-

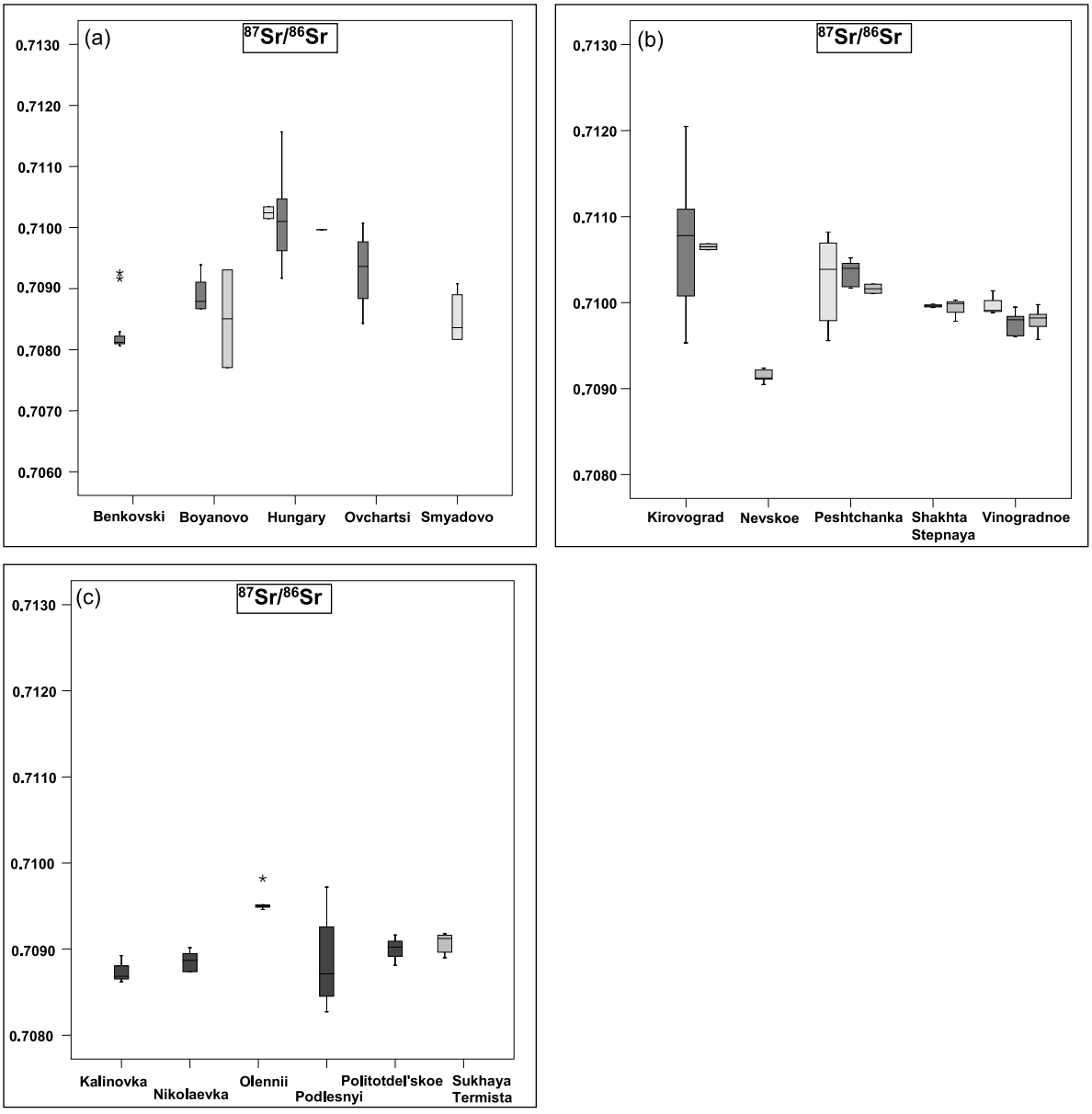


Fig. 4.21 | $^{87}Sr/^{86}Sr$ ranges based on chronological differences (Copper Age/Eneolithic = light grey, Early Bronze Age/Yamnaya = dark grey, Middle Bronze Age = light medium grey, Catacomb culture = medium grey, Poltavka = light black, Novotitarovskaya = black) in the Carpathian-Balkan region (a), North Pontic region (b) and Russia (c).

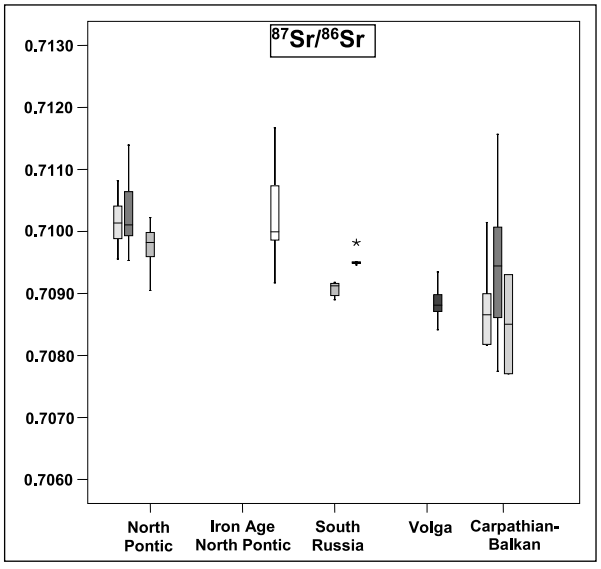


Fig. 4.22 | $^{87}Sr/^{86}Sr$ ranges based on chronological differences on a regional scale (Copper Age/Eneolithic = light grey, Early Bronze Age/Yamnaya = dark grey, Middle Bronze Age = light medium grey, Catacomb culture = medium grey, Poltavka = light black, Novotitarovskaya = black, Scythians = white).

lithic and Yamnaya skeletons (Fig. 4.22). However, the observed variations are most likely to arise from site-related local strontium signature variations.

In general, $^{87}Sr/^{86}Sr$ values according to chronological groups vary significantly ($F = 4.83$, $p < 0.001$; one-way ANOVA), and on a regional scale in the North Pontic ($F = 5.39$, $p = 0.002$; one-way ANOVA). A Tukey's HSD post hoc test reveals, however, that only Yamnaya and Developed Catacomb culture vary on a 5% level of significance ($p = 0.002$). There are also statistical differences for the Carpathian-Balkan region ($F = 4.43$, $p = 0.02$; one-way ANOVA), between the Eneolithic and the Early Bronze Age samples ($p = 0.02$). It should be born in mind, however, that these differences may be due to geographical location.

4.3.4.7 Strontium concentrations

For this study, all enamel samples and a selection of dentine samples underwent concentration measurements of both ^{87}Sr and ^{88}Sr. In total, 189 human enamel samples and six faunal enamel samples were analysed (cf. Appendix A). To check reproducibility, six of the 189 human enamel samples were verified by double measurements. The reproducibility error for ^{88}Sr did not exceed 8 ppm. For human dental enamel the amount of ^{88}Sr varied between 40 and 1111 ppm with a mean value of 191 ± 127 ppm (1σ). Only three samples yielded a value of more than 500 ppm. ^{88}Sr concentrations were found to be between 228 to 654 ppm for the faunal enamel samples. The mean value for the six faunal enamel samples was 469 ± 112 ppm (1σ). In addition, one human bone sample, 67 human and six faunal dentine samples were analysed. The ^{88}Sr mean value for the human dentine samples was 621 ± 451 ppm (1σ, excluding outlier results > 2000 ppm) with a range between 62 ppm and 4535 ppm. Only two samples exceeded 2000 ppm. The mean ^{88}Sr value for the six faunal dentine samples was slightly higher, at 697 ± 130 ppm (1σ). The values range from 601 ppm to 948 ppm. The bone sample showed a value of 864 ppm.

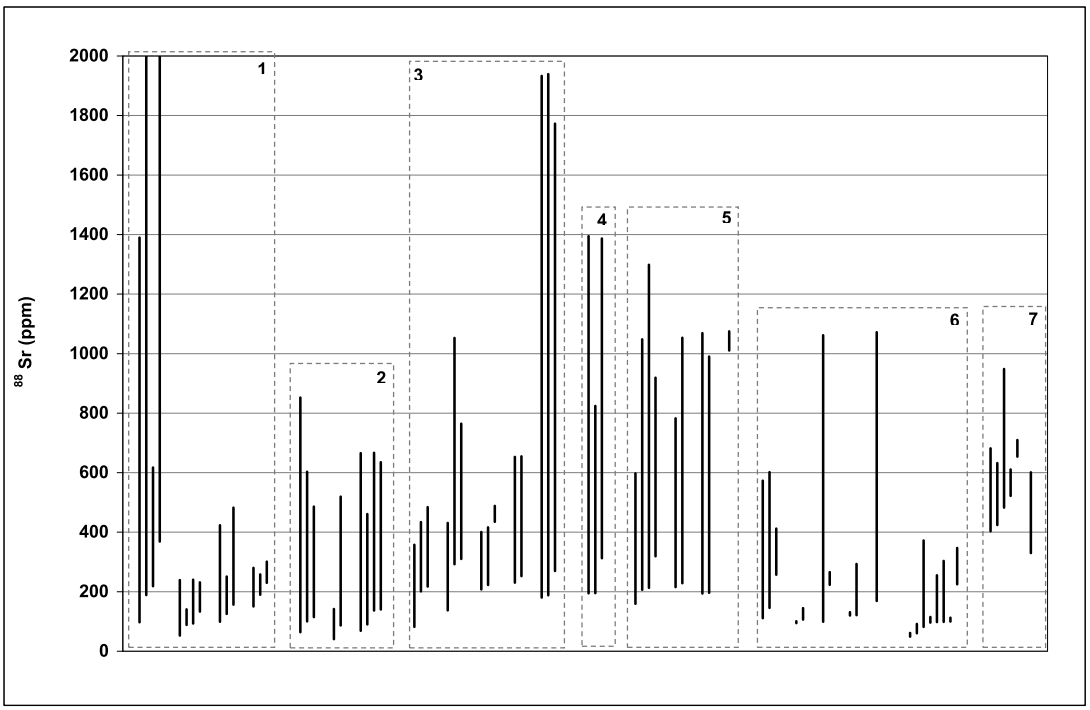


Fig. 4.23 | Differences in the ^{88}Sr concentration of tooth enamel and dentine from 67 humans and five horses from Berel', Kazakhstan, and one horse from the kurgan Sugokleya in Kirovograd, Ukraine. Sample regions are defined by borders: the Eneolithic/Bronze Age sites in Bulgaria (1), Hungary (2), Ukraine (3), Russian Kuban (4), Russian Volga (5), the Iron Age sites in Ukraine and Kazakhstan (6), and the faunal samples (7).

Both enamel and dentine was analysed from 67 human and 6 faunal samples (Fig. 4.23). The differences between enamel samples and dentine samples had a mean of 542 ± 426 ppm (1σ) for human and 228 ± 148 ppm (1σ) for faunal samples. On the basis of her results, J. Montgomery (2002, 340–341) suggested that the enamel Sr is derived predominantly from plants and the water source due to the impact of the food components on the strontium isotope ratios. While animal products such as milk and meat have relatively low Sr concentrations, plants and water concentration have higher ones. These proportions are transferred to the consumers. There have been few analyses of Sr concentration in food components, though it has been addressed in some studies (e.g. Evans/Tatham, 2004; Evans et al., 2007). In this study, Sr concentration measurements were taken on human and faunal tooth enamel, on dentine and on bone. Possible food sources were not analysed which makes an interpretation of the results difficult. Here, analysis of Sr concentrations is used to identify intra-site variation caused by post-mortem Sr uptake. Significant differences in concentrations were found between sites and regions, which can be explained by the variations in geology.

67 human samples is a very small sample size, especially when making comparisons on an intra-site scale. The variation in the concentration of strontium ranges from 7 ppm to 4346 ppm. The high mean of 1043 ppm is caused by extremely high concentrations in a small number of dentine samples. There are obvious variations on an inter-site scale but also, to a lesser extent, between regions. For the Eneolithic and Bronze Age sites in Bulgaria a rather high mean value of 759 ppm is caused by the very high mean of 2275 ppm for Benkovski. The mean values of the other Bulgarian sites (Boyanovo 121 ppm, Ovchartsi 259 ppm, Smyadovo 90 ppm) are much lower. The mean value of the Hungarian

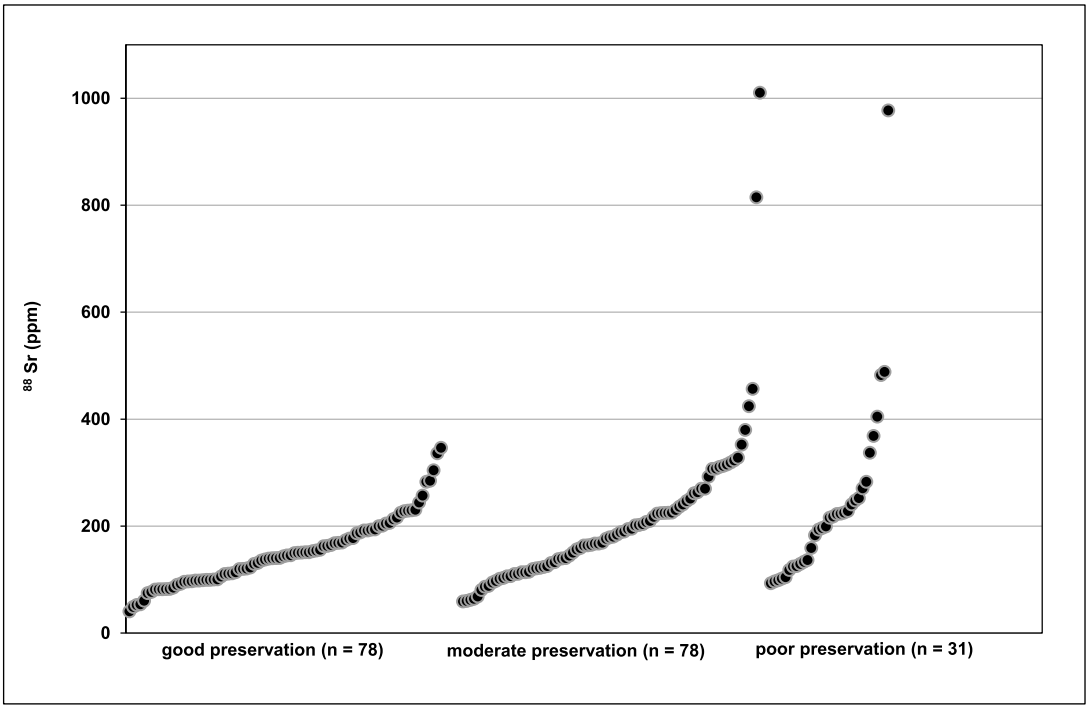


Fig. 4.24 | ^{88}Sr concentrations in the tooth enamel from the human samples. Teeth with good preservation (n = 80) feature a mean of 153 ppm ± 66, those with moderate preservation (n = 78) a mean of 210 ppm ± 145 and teeth with poor preservation (n = 31) a mean of 247 ppm ± 171.

samples is 497 ppm. The relatively high mean value of 604 ppm for the Ukrainian samples is caused by the mean value of 1669 ppm for Nevskoe, whereas the differences in the ^{88}Sr concentrations of enamel and dentine at the sites from Southern Central Ukraine average at 313 ppm. Olennii, in the Kuban region, is another site with a huge difference of 968 ppm between the concentrations in enamel and dentine. In the Volga region, the values have a mean of 681 ppm. The Scythian sites in the territory of Ukraine have a mean strontium concentration of 321 ppm, the human samples from Berel' having a mean of 106 ppm. Altogether, the mean of 226 ppm for all Scythian samples is much lower than that of the Eneolithic and Bronze Age samples. This might be explained by a better degree of preservation of the Scythian material though, at least in the North Pontic, the underlying geology and soil type is the same for the samples of both periods. The same was done for some of the faunal samples. ^{88}Sr concentrations were determined for the five horses from Berel' and for the horse in grave 5 of the kurgan Sugokleya in Kirovograd. Normally, faunal teeth show higher ^{88}Sr concentrations than human teeth. The differences between the ^{88}Sr concentrations in enamel and dentine in the faunal samples are smaller than in the human ones. The average concentration for the six samples is 228 ppm with a range from 56 ppm to 466 ppm.

Results from 189 human teeth with definable preservation suggested the possibility of a correlation between the state of preservation and the ^{88}Sr concentration in the tooth enamel (Fig. 4.24). The 80 well preserved teeth had an average tooth enamel ^{88}Sr concentration of 151 ppm. The 78 moderately preserved teeth had an average ^{88}Sr concentration of 207 ppm and the 31 poorly preserved teeth had an average ^{88}Sr concentration of 239 ppm in the tooth enamel, showing a progressive increase in

^{88}Sr concentration as preservation declines. A Levene test showed that the null hypothesis (where the mean variation of the three groups of good, moderate and poor preservation are equal) can be rejected on a 5% level of significance ($F = 5.76$, $p = 0.004$; Levene test). Therefore, no one-way ANOVA was necessary but a Kruskal-Wallis test revealed statistically significant differences between the groups ($F = 15.72$, $p < 0.001$). Thus the assertion that ^{88}Sr concentrations increase as the state of preservation declines can be statistically proven. The same is true for the samples in Bulgaria and the North Pontic region, which shows that the pattern holds true, though to a lesser extent, even when the outliers are excluded.

4.3.5 Biological measurements of $^{87}Sr/^{86}Sr$

4.3.5.1 Published $^{87}Sr/^{86}Sr$ data

The TRACE project gathered data on trace element concentrations and isotope ratios of Sr, O, H, and S from around 700 natural mineral waters in Europe. This data was used to produce a map showing the $^{87}Sr/^{86}Sr$ signatures overlying the solid geology of Europe (Voerkelius et al., 2010, 936 fig. 1) (Fig. 4.25). The TRACE project was preceded by a previous project that mapped the predicted $^{87}Sr/^{86}Sr$ signatures of different geological regions in the United States (Beard/Johnson, 2000) and the United Kingdom (e.g. Evans et al., 2010), but was solely based on the surface geology. By using water samples rather than relying solely on rocks and sediments, the map of Voerkelius and colleagues offers a better representation of biologically available strontium. There is a general agreement between the $^{87}Sr/^{86}Sr$ ratios in the geology and the water samples, but the values do not necessarily always match the geology. The lowest approximate ratio from 0.702 to 0.707 is given for Cenozoic, Mesozoic and Palaeozoic volcanics, ophiolites and Cenozoic intrusives followed by Mesozoic sediments with a range from 0.707 to 0.709. Cenozoic sediments are slightly more radiogenic with $^{87}Sr/^{86}Sr$ ratios between 0.709 and 0.711. This is followed by Middle Upper Palaeozoic sediments and Mesozoic metamorphic rocks, which are uncommon in the study area, with a range from 0.711 to 0.713. The highest radiogenic values occur on Lower Palaeozoic sediments, Palaeozoic metamorphic rocks and intrusives (0.713 to 0.720) and Precambrian sediments and metamorphic rocks (0.720 to 0.780).

The map is very useful when looking for expected $^{87}Sr/^{86}Sr$ ratios in the study area, even though the eastern borders of the map are marked by Poland and Hungary, which means that only Bulgaria, Romania and Hungary are included in the map. However, knowing the geology, the $^{87}Sr/^{86}Sr$ ranges can be estimated for the regions of this study that are further east.

Many $^{87}Sr/^{86}Sr$ ratios are published for samples from different geologies in Central Europe. In the absence of known $^{87}Sr/^{86}Sr$ proxies for the study area, rocks of similar types and ages can be compared to find expected 'local' $^{87}Sr/^{86}Sr$ ranges. Some of the typical $^{87}Sr/^{86}Sr$ values of the most relevant rock types are listed here (cf. Vohberger, 2011, table 2 incl. references): $^{87}Sr/^{86}Sr$ values in volcanic rock samples range between 0.70353 ± 0.0009 in rocks in Balmuccia, Italy and 0.7085 in measured in sediments in Naples, Italy. V. Oelze found the biosphere samples from the region around the Hohentwiel volcano range between approximately 0.706 and 0.708 (Oelze, 2012, 70, fig. 6.4, 6.5). Values from carbonate rocks are slightly more radiogenic and produce values from 0.7079 in plants and snails from Alicante, Spain and 0.70976 ± 0.0004 in horse and cattle teeth from Dublin, Ireland. A strontium biosphere range of 0.709 to 0.710 for regions of Jurassic sediments in Central England was suggested by

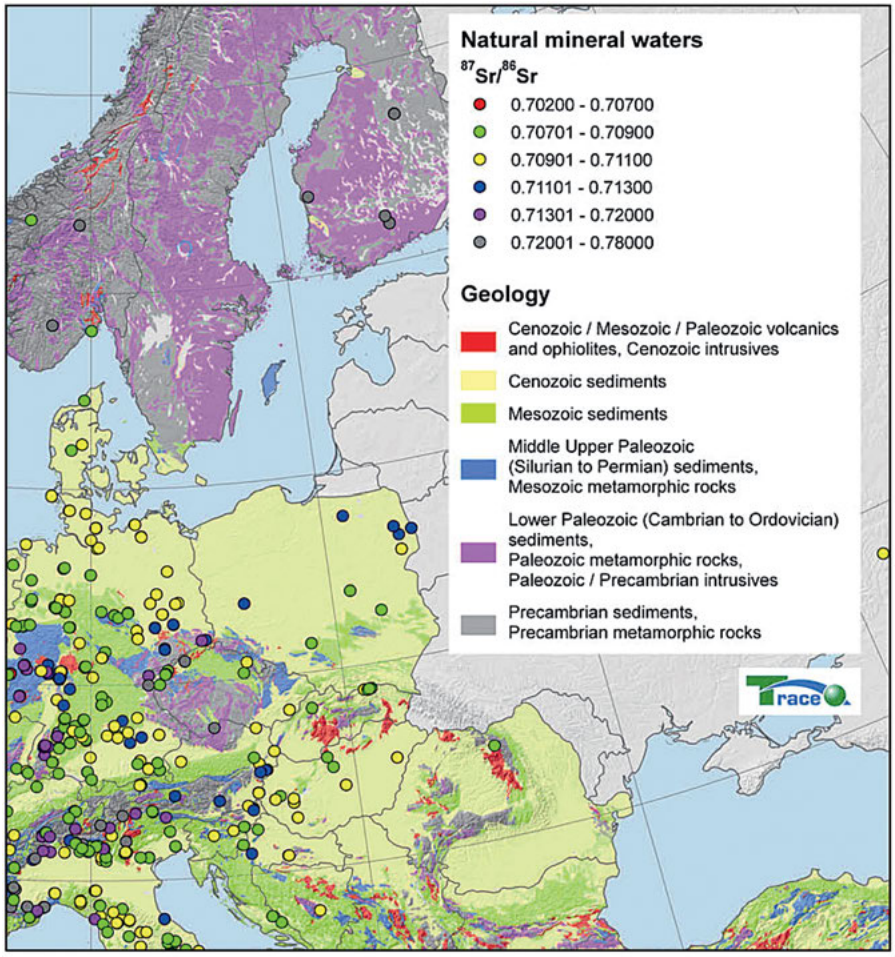


Fig. 4.25 | Map extract from Voerkelius et al., 2010, fig. 1, showing the $^{87}Sr/^{86}Sr$ data of collected European natural mineral waters from the TRACE project and a spatial prediction based on a GIS based geological map.

J. Evans and colleagues (Evans et al., 2010). Oelze found a range of approximately 0.707 to 0.709 for Late Jurassic limestone in South Germany (Oelze, 2012, 70, fig. 6.4, 6.5). Values from 0.70838 in snails in Dillingen, Germany (Price et al., 2002) to 0.70997 ± 0.0002 in pigs in Wang, Germany (Bentley/Knipper, 2005) can be regarded as characteristic for loess regions. Analyses undertaken near the study area gave an $^{87}Sr/^{86}Sr$ ratio for humans based on loess in Budapest, Hungary of 0.70984 ± 0.0004 (Price et al., 2004). *Grundgebirge* and granite are expected to have the highest $^{87}Sr/^{86}Sr$ ratios. Values of 0.7345 in rock in the Harz Mountains, Germany or 0.72217 in pigs in the Bavarian Forest, Germany (Bentley/Knipper, 2005) are characteristic for *Grundgebirge*, whereas values between 0.71163 ± 0.0008 in animal bones from Hostivicé, Czech Republic and 0.77884 ± 0.012 in sediments in Buskbäcken, Sweden are typical for granites.

Very few studies using strontium isotope analysis have taken place in the study region and most of them were initiated within the last few years, the results are generally not yet published. J. Giblin worked on the Neolithic/Eneolithic transition in Eastern Hungary. To estimate the 'local' range of her study area she analysed 18 faunal samples covering seven faunal species from three sites that ranged

from 0.70933 to 0.71026. The measured $^{87}Sr/^{86}Sr$ ratios in modern water samples from the Tisza and Danube rivers range from 0.7089 to 0.7096 (Giblin, 2004, 9 table 3.1; Giblin, 2009, 494 table 1 see Palmer/Edmond, 1989; Price et al., 2004). V. A. Trifonov and colleagues investigated the dolmen Kolikho in the western Caucasus Mountains and though they lie just outside the study area, the data is relevant here. 47 human bone samples were selected for $^{87}Sr/^{86}Sr$ analysis. The 'local' $^{87}Sr/^{86}Sr$ range, established by snail shells from the vicinity of the site, ranged between 0.707 and 0.708 (pers. comm. V. A. Trifonov).

4.3.5.2 Estimation of the 'local' $^{87}Sr/^{86}Sr$ range and identification of 'locals' and 'non-locals'

4.3.5.2.1 Eneolithic and Bronze Age

Bulgaria (Fig. 4.26)
One plant and one sediment sample were taken in the course of the excavation at Benkovski. The dentine of four human teeth served as additional references. With a mean $^{87}Sr/^{86}Sr$ ratio of 0.70810 ± 0.00061 (2σ), the results range from 0.70745 to 0.70841. The dentine samples are very similar. $^{87}Sr/^{86}Sr$ ratios from the sediment sample and the fauna are comparable, but the plant sample is slightly less radiogenic. Possible contamination of the sediment and plant material due to fertilizers or pollution cannot be excluded since samples were taken from cultivated land. In Boyanovo, the 'local' $^{87}Sr/^{86}Sr$ range was established by one sediment sample, recent snails and three dentine samples, which averaged at 0.70844 ± 0.00067 (2σ) and ranged from 0.70812 to 0.70893. One sediment and one plant sample were taken close to Ovchartsi and supplemented by three dentine samples to establish a local $^{87}Sr/^{86}Sr$ ratio. The dentine and plant samples are comparable, whereas the sediment is substantially less radiogenic. The mean of all reference samples was 0.70946 ± 0.00181 (2σ) with a range from 0.70785 to 0.70995. Ignoring the less radiogenic sediment there is a mean of 0.70986 ± 0.0002 (2σ). The 'local' $^{87}Sr/^{86}Sr$ range for Smyadovo was established by the analyses of one sediment, one plant and three dentine samples. They gave a mean $^{87}Sr/^{86}Sr$ ratio of 0.70819 ± 0.00048 (2σ) and a range between 0.70779 and 0.70852. In this instance, results from the dentine and both environmental samples were very similar. According to the TRACE $^{87}Sr/^{86}Sr$ map, a local signature of 0.709 to 0.711 (Cenozoic sediments) would be expected for the sites of Benkovski, Boyanovo and Ovchartsi, but more radiogenic rocks with values above 0.711 nearby could result in a mixed signal. The lower than predicted local ranges of Benkovski and Boyanovo could represent a mixed signal from Cenozoic sediments and the northern and eastern Mesozoic geology. The measured local values from Ovchartsi correspond better with those expected from the TRACE map, as do those from Smyadovo, which fit within the characteristic Mesozoic range of 0.707 to 0.709 very well. The nearby Balkan Mountains are represented by a wide range of $^{87}Sr/^{86}Sr$ values that lie between 0.707 and 0.720.

The next step in interpreting the results of strontium isotope analysis is to compare the results from the enamel with the 'local' $^{87}Sr/^{86}Sr$ signature. Thus, 'local' and 'non-local' individuals can be identified. The local $^{87}Sr/^{86}Sr$ range is rather similar for the sites Benkovski and Smyadovo. The range of biologically available $^{87}Sr/^{86}Sr$ is only slightly more radiogenic at Boyanovo. This is notable because the underlying geology of the four Bulgarian sites is quite variable. The biologically available $^{87}Sr/^{86}Sr$ range at Ovchartsi is more radiogenic than that of the other three sites. In Benkovski, the two sampled teeth from grave 3 in kurgan 2 lie outside the local strontium signature but also lie outside the range of the other

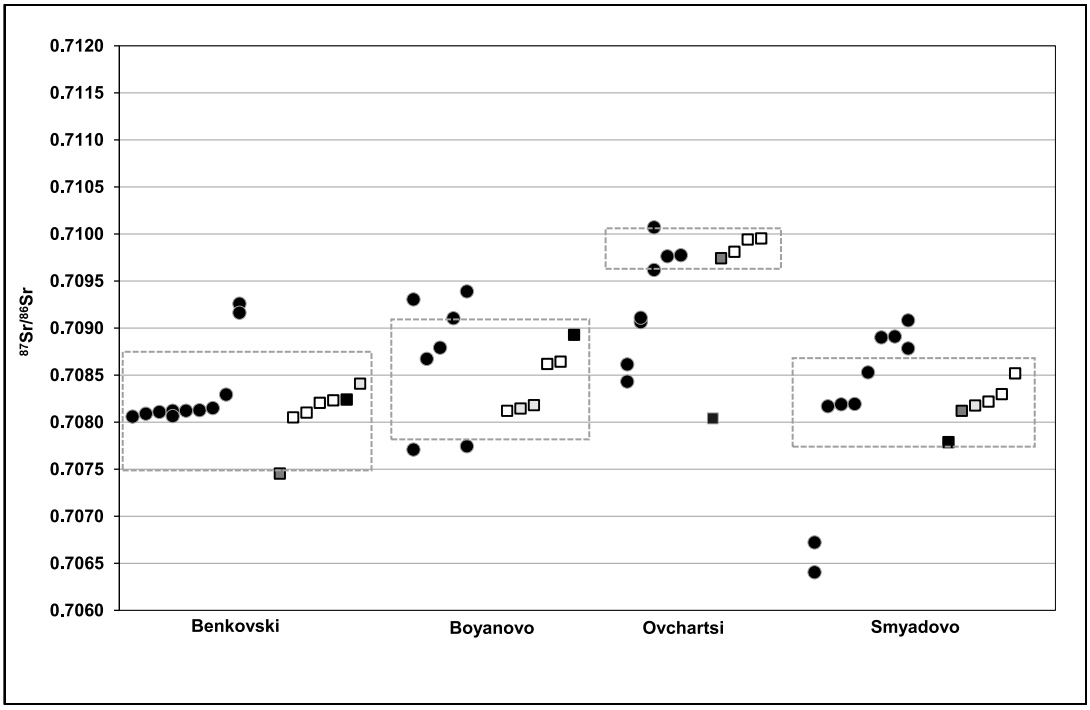


Fig. 4.26 | $^{87}Sr/^{86}Sr$ data for tooth enamel and sampled reference material used to establish the expected 'local' biologically available $^{87}Sr/^{86}Sr$ at the four Bulgarian sites. Grey rectangles border the 'local' range of each site.
Tooth enamel samples are represented by black circles and arranged in a line if belonging to the same individual. Squares represent the reference samples: Sediments (black), plants (dark grey), faunal samples (light grey) and dentine samples (white).

enamel samples there. This individual is clearly different to the others. At Boyanovo, two individuals (grave 4 and 14), lie outside the local range. In both individuals, one value lies below the local range, while the other lies above the range, which indicates a huge intra-individual variability. The $^{87}Sr/^{86}Sr$ value for the sediment sample from Ovchartsi did not fit with the other reference material and so was not used to define the local signature, which was then the most radiogenic local signature of all the Bulgarian sites. Graves 1 and 15 (skull west) lie outside the local range, with both sampled teeth from the two individuals giving lower $^{87}Sr/^{86}Sr$ ratios than expected. Though the values are less radiogenic than would be expected from the local signature, the values for these two individuals match the local strontium signatures of the other three Bulgarian sites and the sediment sample that was dismissed in establishing the local signature fits well with the local signatures for the other sites. The local strontium signature for Smyadovo is more reliable, making grave 22 a clear outlier and graves 6, 13, and 16 very probable outliers.

Hungary (Fig. 4.27)
Two sheep bones, one cattle tooth, one sediment and one plant sample from the area surrounding Sárrétudvari as well as four dentine samples were selected to establish the 'local' $^{87}Sr/^{86}Sr$ signature. One of the sheep bones was certainly archaeological, the cattle tooth was recent or archaeological and though the sediment sample was taken from a cultivated field, all of the reference results were comparable. However, because of the high risk of modern contamination by fertilizers, the sediment sample was

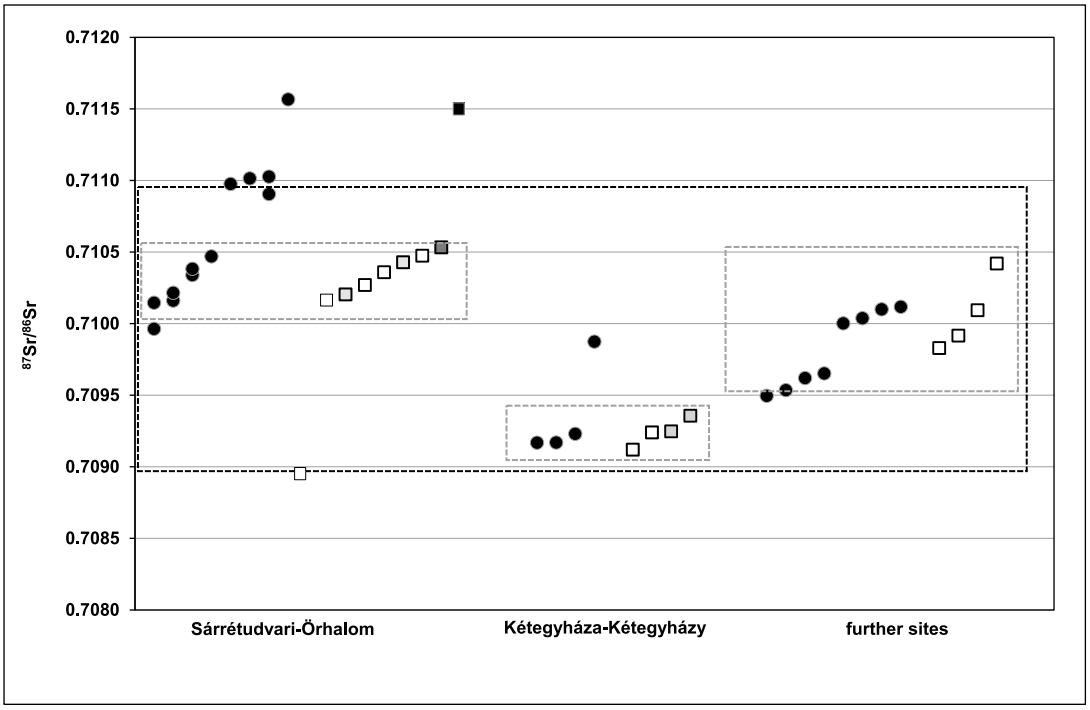


Fig. 4.27 | $^{87}Sr/^{86}Sr$ data for tooth enamel and sampled reference material used to establish the expected 'local' biologically available $^{87}Sr/^{86}Sr$ at the sites in the Eastern Hungarian Plain. Grey rectangles border the 'local' range of each site. The black rectangle represents the overall 'regional' $^{87}Sr/^{86}Sr$ range. Tooth enamel samples are represented by black circles and arranged in a line if belonging to the same individual. Squares represent the reference samples: Sediments (black), plants (dark grey), faunal samples (light grey) and dentine samples (white).

ignored for the definition of the 'local' range of biologically available strontium. The mean $^{87}Sr/^{86}Sr$ ratio of all baseline samples was 0.71031 ± 0.00125 (2σ) and 0.71035 ± 0.00028 (2σ) ignoring the outliers, the sediment and the cattle tooth. All reference samples ranged between 0.70896 and 0.71139. For the group of burial mounds in Kétegyháza, the mean of one archaeological sheep astragal and a prehistoric dog's tooth plus two dentine samples was 0.70924 ± 0.00019 (2σ) and ranged from 0.70912 to 0.70936.

The geology of the Eastern Hungarian Plain is homogeneous over a large area and so the results of the references plus four dentine values from the further sites in that sample area can be looked at as a whole. The overall mean for the region is 0.70998 ± 0.00100 (2σ) with a range of 0.70912 to 0.71053 excluding the two outlier references from Sárrétudvari. J. I. Giblin established a local $^{87}Sr/^{86}Sr$ ratio of 0.70933 to 0.71026 for her study sites in Eastern Hungary based on 18 faunal samples and one water sample (Giblin, 2009, 494), which is more limited than our 'local' range. According to Voerkelius and colleagues the Cenozoic sediments of the plain result in biologically available $^{87}Sr/^{86}Sr$ values of 0.709 to 0.711 (Voerkelius et al., 2010), which fits more closely with those found in this study. The soil sample from Sárrétudvari exceeds this range and the cattle tooth lies below this range, which provides another reason for ignoring these two references when establishing the local range. The Carpathian Mountain ranges vary, with regions of Cenozoic, Mesozoic and Palaeozoic volcanics and very low radiogenic values between 0.702 and 0.707 and Mesozoic sediments ranging between 0.707 and 0.709. Highly radiogenic values, however, are given on the Lower Palaeozoic sediments and metamorphic rocks (0.713 to

0.720) as well as Precambrian rocks (0.720 to 0.780). Altogether, there is a broad range from 0.702 to 0.780 of expected $^{87}Sr/^{86}Sr$ values for the Carpathian Mountains.

Considering the 'local' $^{87}Sr/^{86}Sr$ ranges of the single sites, there is a great variability between higher radiogenic values in Sárrétudvari and low radiogenic values in Kétegyháza. This is striking since the geology of the East Hungarian Plain is rather homogeneous and suggests that there is a certain variation in the biologically available $^{87}Sr/^{86}Sr$ within the region with more radiogenic values in the northeast of the study area and less radiogenic values in the southeast. Interpreting the 'local' site ranges separately, four samples are above and one lies below the range of Sárrétudvari. The outlier value of Kétegyháza is more radiogenic than the 'local' range but consistent with the range determined by the dentine samples of the further sites of the plain and even less radiogenic than Sárrétudvari.

To summarize the findings, only four of the individuals from Sárrétudvari, burials 4, 7, 9 and 11, lie above the range that is considered to reflect the biologically available strontium for the Eastern Hungarian Plain. The only real outlier is burial 11. The other samples are probably the result of a mixed signal between lowlands and uplands.

North Pontic region (Fig. 4.28)

The kurgan Sugokleya in Kirovograd had extremely varied $^{87}Sr/^{86}Sr$ ratios in the sampled tooth enamel and various reference materials were analysed from the surrounding area to establish a local $^{87}Sr/^{86}Sr$ signature. All references match very well. One snail, two sediment samples and one plant sample were taken in addition to one archaeological horse tooth from grave 5 of the same kurgan. A vertical section was sampled from the horse tooth and was included as an addition to other reference materials, in the knowledge that using a horse from a supposedly mobile society might be questionable when establishing a 'local' signature. Three dentine and two bone samples from the human individuals were also taken. The mean of the references is 0.71025 ± 0.00021 (2σ) with a range from 0.71008 to 0.71041.

Two sediment, one plant and two teeth from a cattle skull from an excavation of an 18th century settlement in the vicinity were analysed to establish the 'local' $^{87}Sr/^{86}Sr$ range for Peshtchanka. Three dentine and two bone samples were also sampled. All references are compatible except the cattle teeth. Cattle in the 18th century could have been fed supplementary fodder from elsewhere, which might change their $^{87}Sr/^{86}Sr$ value. Cattle may also have been exchanged or ranged over large areas. With this in mind, the 'local' biologically available strontium range was first estimated including all baseline samples and secondly excluding the cattle teeth. The mean value for all references is 0.71078 ± 0.0006 (2σ) with a range from 0.71043 to 0.71151. Excluding the cattle, the mean was 0.71070 ± 0.00032 (2σ) and the range between 0.71043 and 0.71096.

One recent snail, one sediment sample from the remains of burial mound 4, one plant sample (oak leaves) from a nearby forest, one bone and two dentine samples were used to establish the 'local' $^{87}Sr/^{86}Sr$ range of Shakhta Stepnaya. Though the plant sample has the risk of contamination due to its vicinity to a street and a train track, all reference samples cluster quite closely. The mean $^{87}Sr/^{86}Sr$ value for the references is 0.71000 ± 0.00118 (2σ), and they range between 0.70914 and 0.71094. If the outlier plant sample were ignored, the mean would be 0.70981 ± 0.00081 (2σ) with a range from 0.70914 to 0.71024.

A variety of references was available for the burial mounds 3 and 24 in Vinogradnoe. Two rodent teeth, one shell, three sediment, one plant and one dog tooth were sampled from within a 10 km radius. The results cluster well except for the shell and one of the rodents. The rodent may have been contami-

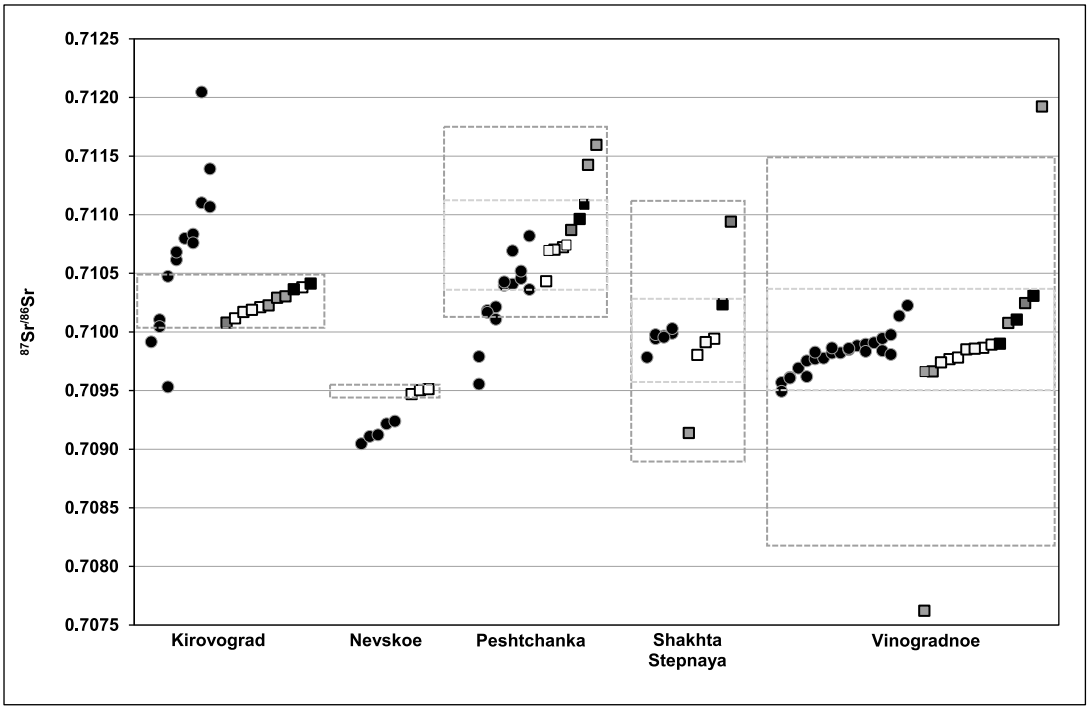


Fig. 4.28 | $^{87}Sr/^{86}Sr$ data for tooth enamel and sampled reference material used to establish the expected 'local' biologically available $^{87}Sr/^{86}Sr$ at the sites in the North Pontic region. Grey rectangles border the 'local' range of each site. Tooth enamel samples are represented by black circles and arranged in a line if belonging to the same individual. Squares represent the reference samples: Sediments (black), plants (dark grey), faunal samples (light grey), bone samples (beige) and dentine samples (white).

nated by fertilizers as it was found near a cultivated field. The shell was found in the profile of a loam pit and might be much older in date and thus reflect the strontium ratio of the sea of an older time period. Three dentine and four bone samples were also analysed to investigate diagenetic changes in both tissues. It seems that bone and dentine are diagenetically altered in a similar way. The combination of all references yields a mean $^{87}Sr/^{86}Sr$ ratio of 0.70991 ± 0.00167 (2σ) with a range from 0.70762 to 0.71192. Ignoring the two outliers, the shell and the rodent, the mean is 0.70993 ± 0.00039 (2σ).

The measured 'local' $^{87}Sr/^{86}Sr$ ratios match the predicted signals of the TRACE map (Voerkelius et al., 2010) very well. The homogeneous Cenozoic sediments around Shakhta Stepnaya and Vinogradnoe result in equally homogeneous local strontium signatures. The more radiogenic reference values from Peshtchanka reflect the mixture of Cenozoic sediments and a more radiogenic geology with $^{87}Sr/^{86}Sr$ ratios over 0.711. This, interestingly, is not mirrored in the reference samples from Kirovograd but in the tooth enamel samples from that site, where the higher values probably reflect both underlying geologies.

Due to the absence of reference material from Nevskoe and other sites from Eastern Ukraine, three dentine samples were analysed, resulting in almost identical numbers. The mean of the dentine is 0.70950 ± 0.00005 (2σ) with a range of 0.70947 to 0.70951. This range is extremely narrow. Geologically, Nevskoe differs from the Central Ukrainian sample sites. The Mesozoic sediments predict a local $^{87}Sr/^{86}Sr$ signature between 0.707 and 0.709. The peripheral Cenozoic sediments may be the cause for the slightly elevated values.

The reference samples from the five sites in the Northern Pontic region where enamel samples cluster in a narrow range do not necesarily cluster so closely. There is a narrow range of references in Nevskoe, where there is also a narrow range of enamel values, but all the enamel samples are less radiogenic, which would indicate that those individuals spent a significant proportion of time in their youth on geologies with lower $^{87}Sr/^{86}Sr$ ratios. In Vinogradnoe, the tightly clustered tooth enamel samples are comparable with the references. Only two outlier references widen the 'local' Sr range. All the enamel samples fall within the biologically available 'local' strontium range, even when the outliers are included. At Kirovograd the 'local' $^{87}Sr/^{86}Sr$ signature is defined within a narrow range, which is rather surprising considering the large variety in the tooth enamel values. All the human enamel samples except three, the first tooth from burial 20 and both teeth from burial 5, lie outside the limits of the local $^{87}Sr/^{86}Sr$ signature and all, except the second tooth of grave 20, are more radiogenic. The latest grave, burial 13, might be local as the values lievery close to the 'local' range. Peshtchanka and Shakhta Stepnaya have wider ranges in their 'local' biologically available $^{87}Sr/^{86}Sr$ signature. While results from one individual in Peshtchanka, burial 14, lie outside the 'local' range, all enamel values in Shakhta Stepnaya are within the 'local' range. In Peshtchanka, differences in $^{87}Sr/^{86}Sr$ ratios between the two teeth sampled from each individual are more exaggerated in the Eneolithic than for the Yamnaya samples, which show little variability. The sites are located in an area of several hundred square kilometres, therefore the 'local' Sr ranges cannot be combined to one regional $^{87}Sr/^{86}Sr$ signature. Even the 'local' ranges for Peshtchanka and Shakhta Stepnaya are rather diverse despite being geographically close.

Excluding the outlier references in Peshtchanka, Shakhta Stepnaya and Vinogradnoe more closely defines the 'local' $^{87}Sr/^{86}Sr$ ranges. If the cattle tooth in Peshtchanka is ignored, all enamel results from burials 10 and 12 lie outside the local range. If the rodent and the shell are ignored in Vinogradnoe, only one grave has less radiogenic ratios than the local signature. While the first tooth of kurgan 24, grave 15, skeleton 2, lies outside the local range, the second tooth has an $^{87}Sr/^{86}Sr$ ratio at the lower edge of the local signature. The other enamel values cluster very tightly and can therefore be considered as locals.

Volga region (Fig. 4.29)
Three of the four sites in the Middle Volga region are situated in the vicinity of Samara. Despite the varying underlying geology and the distance to the fourth site, Podlesnyi, the results for the reference samples conform well and might allow the creation of a combined data set of all Volga sites. This combined data set has a mean $^{87}Sr/^{86}Sr$ value of 0.70930 ± 0.00048 (2σ) with a spread from 0.70902 to 0.70970. Differences in the underlying geology suggest that the sites be discussed individually. For Kalinovka I the 'local' signature established by samples from two faunal bones and two human dentine samples ranging from 0.70902 to 0.70929, is 0.70912 ± 0.00023 (2σ). As both dentine samples are very similar to the animal bones, it can be assumed that the four samples together give a good idea of the local burial environment. The $^{87}Sr/^{86}Sr$ range of the four dentine reference samples from Nikolaevka III lies between 0.70947 and 0.70968, while the mean is 0.70960 ± 0.00019 (2σ). Three dentine samples were taken from Podlesnyi. The 'local' $^{87}Sr/^{86}Sr$ signature ranges between 0.70904 and 0.70934 with a mean of 0.70915 ± 0.00034 (2σ). The predicted $^{87}Sr/^{86}Sr$ signature for the geology, between 0.709 and 0.711 or higher, matches the reference values but not the less radiogenic tooth enamel ratios. This might be explained by an influence of the neighbouring Mesozoic rocks or movement from an area with a lower $^{87}Sr/^{86}Sr$ ratio. Two dentine samples were analysed from Politotdel'skoe, which yielded similar results and a mean of 0.70929 ± 0.00002 (2σ). They are more radiogenic than the tooth enamel, and so the burial environment can be considered as more radiogenic. Two dentine samples do not form a

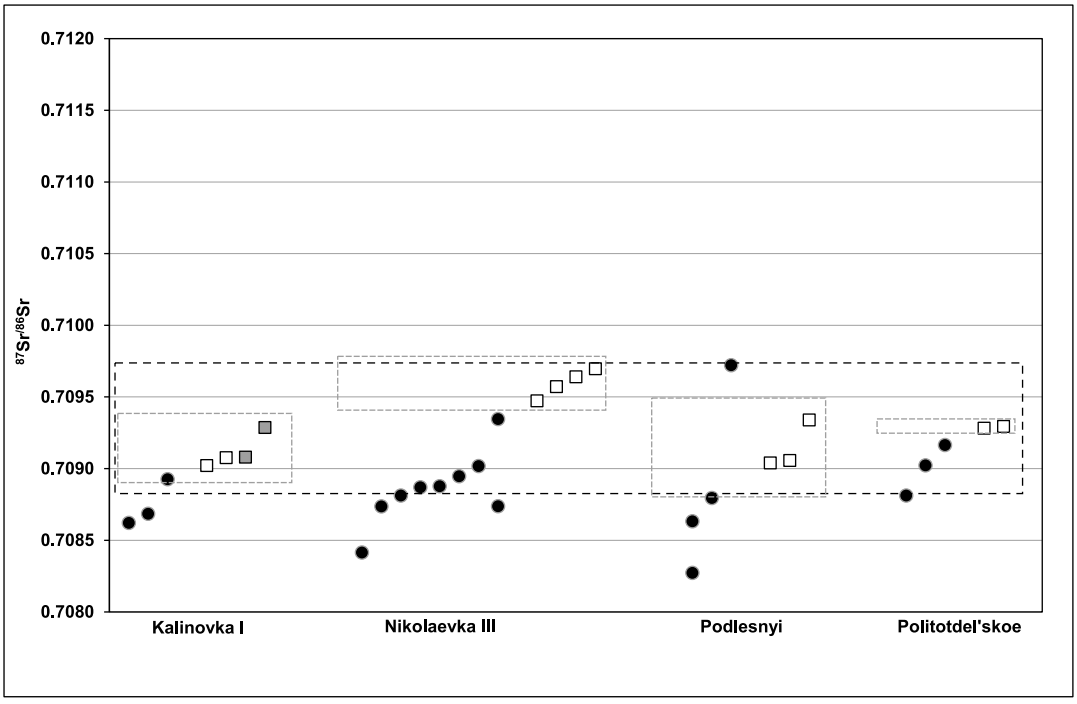


Fig. 4.29 | $^{87}Sr/^{86}Sr$ data for tooth enamel and sampled reference material used to establish the expected 'local' biologically available $^{87}Sr/^{86}Sr$ for the sites in the Volga region. Grey rectangles border the 'local' range of each site. The black rectangle represents the overall 'regional' $^{87}Sr/^{86}Sr$ range. Tooth enamel samples are represented by black circles and arranged in a line if belonging to the same individual. Squares represent the reference samples: Faunal samples (grey) and dentine samples (white).

credible basis. The range is too narrow for an area that covers at least more than 10 km² and has a varied geology. The geology of the area surrounding Politotdel'skoe predicts a 'local' $^{87}Sr/^{86}Sr$ signature between 0.709 and 0.711, which is a good match for the reference samples.

The sites Kalinovka I, Nikolaevka III and Podlesnyi are situated close to the modern town of Samara. They yield similar but not completely identical 'local' $^{87}Sr/^{86}Sr$ ranges, which would be expected because of the relative geological homogeneity of the region. With the exception of two faunal bones, only dentine samples were available as reference material. Dentine tends to yield very limited local $^{87}Sr/^{86}Sr$ signature ranges and so a combined regional $^{87}Sr/^{86}Sr$ signature range was also estimated, which included all dentine samples and faunal bones from the four sites.

Almost all the $^{87}Sr/^{86}Sr$ values from the enamel samples lie outside the 'local' $^{87}Sr/^{86}Sr$ signatures of each individual site. Only one individual in Kalinovka I is within the estimated 'local' $^{87}Sr/^{86}Sr$ range. This could mean that the burial environment does not reflect the biologically available strontium for the region, or that the enamel was mineralising in another region away from the place of death. The same pattern can be seen at the other sites, where all tooth enamel values lie outside the 'local' Sr range based on the dentine values.

As described above, the limitations of using only dentine to establish a 'local' $^{87}Sr/^{86}Sr$ range, led to a calculation of a regional $^{87}Sr/^{86}Sr$ signature estimated on the basis of the geology and combining all the reference samples. This broader 'local' $^{87}Sr/^{86}Sr$ signature included more enamel samples within

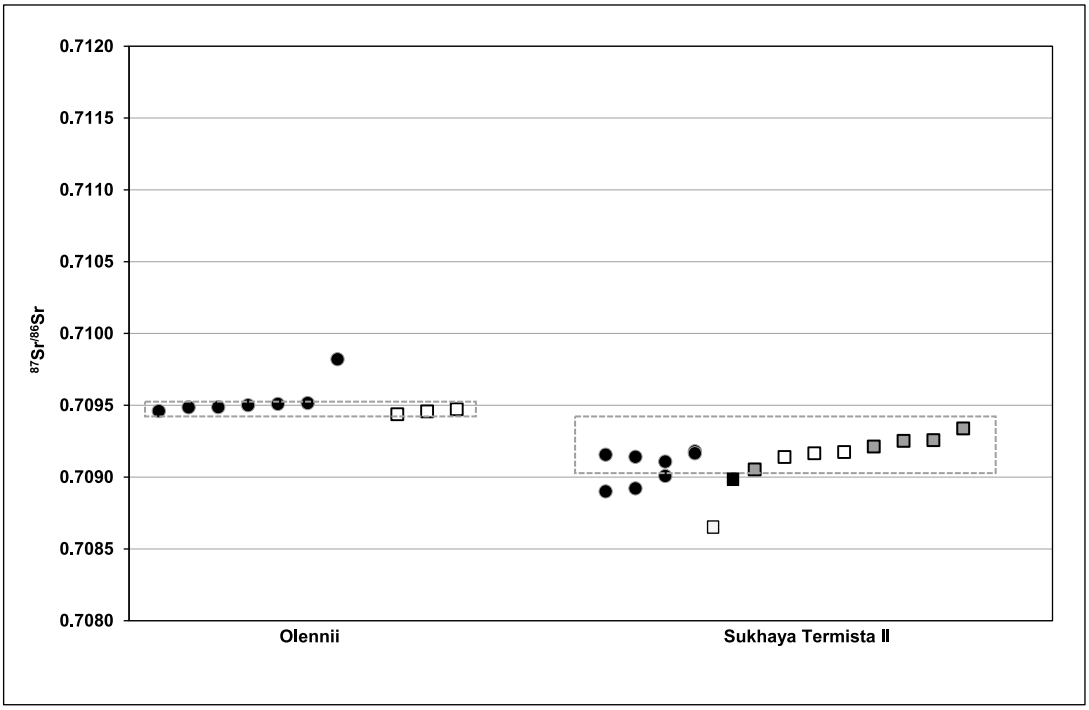


Fig. 4.30 | $^{87}Sr/^{86}Sr$ data for tooth enamel and sampled reference material used to establish the expected 'local' biologically available $^{87}Sr/^{86}Sr$ for the sites Olennii (left) and Sukhaya Termista II (right). Grey rectangles border the 'local' range of each site. Tooth enamel samples are represented by black circles and arranged in a line if belonging to the same individual. Squares represent the reference samples: Sediments (black) and faunal samples (grey). The light grey square symbolizes a section of human tooth enamel sampled of a medieval date. Dentine (from Olennii) and bone (from Sukhaya Termista II) samples are symbolized by white squares.

the 'local' $^{87}Sr/^{86}Sr$ range. In addition to the individual in Kalinovka I mentioned above, five samples in Nikolaevka III, one in Podlesnyi and two in Politotdel'skoe could now be considered as local to the region. Even so, the large number of individuals with $^{87}Sr/^{86}Sr$ ratios outside the regional range is remarkable.

South Russia (Fig. 4.30)
In the absence of any other reference materials from the area around Olennii, three dentine samples were used to establish the 'local' $^{87}Sr/^{86}Sr$ signature which gave a very restricted local range of 0.70942 to 0.70949 and a mean of 0.70946 ± 0.00003 (2σ). This narrow range of results was also exhibited by the results of the enamel samples, which seem to have a totally 'local' signature.

A variety of reference materials were available from Sukhaya Termista II. The references include one sediment and five faunal samples, of which one is a cattle tooth and four are rodent teeth. Supplementary bone samples of three human individuals were selected. In addition, the tooth enamel of a medieval skeleton was analysed for comparison. Interestingly, this sample delivered the only outlier value and was excluded for the establishment of the 'local' range. Differences might infer a non-local origin of some individuals buried in the mound in the medieval period. On the other hand, it could reflect dietary differences over time. This results in a 'local' $^{87}Sr/^{86}Sr$ range of 0.70918 ± 0.00022 (2σ) with values ranging from 0.70898 to 0.70934. The uniform geology of Cenozoic sediments underlying the

southern Russian steppes would suggest local $^{87}Sr/^{86}Sr$ signatures for both sites between 0.709 and 0.711. The Caucasus Mountains have mostly less radiogenic rocks but the results do not reflect this. The references for Sukhaya Termista II, on the other hand, show $^{87}Sr/^{86}Sr$ ratios at the lower end of the predicted range. Even though the enamel values are within the local range, there may be some connection to the Yergueni Hills to the east.

In Olennii, the three dentine values result in an extremely narrow range that is not likely to represent the full $^{87}Sr/^{86}Sr$ ratio range of 'local' biologically available strontium. There is only a little variation within the tooth enamel values, and the only tooth enamel that is less than 0.0005 more radiogenic than the 'local' signature is that of kurgan 2, grave 25b. This individual might possibly be considered to show a non-local influence, but the variation is insufficient to be certain.

The references in Sukhaya Termista II (excluding the medieval tooth enamel) yield a broader, but still limited range of 'local' biologically available $^{87}Sr/^{86}Sr$. The first sampled teeth of the individuals in kurgan 1 grave 5 and kurgan 3 grave 20 and the third molar of kurgan 1 grave 2 are marginally less radiogenic than the 'local' range. The variation is very limited but as the second sampled teeth are within the 'local' $^{87}Sr/^{86}Sr$ signature, a movement to the region of death at a certain point in infancy might be suggested.

4.3.5.2.2 Iron Age

North Pontic (Fig. 4.31)

A common regional $^{87}Sr/^{86}Sr$ signature can be assigned to the North Pontic region because of the uniform nature of its geology. The mean value for all Scythian North Pontic reference samples is 0.71 ± 0.00051 (2σ) with a range from 0.70939 to 0.71039.

The two dentine samples from Babina Mogila feature a mean $^{87}Sr/^{86}Sr$ ratio of 0.70994 ± 0.00001 (2σ, but n =2). For Drana Kokhta the mean $^{87}Sr/^{86}Sr$ value is 0.71013 ± 0.00075 (2σ, n =2) and for Zolotaya Balka 0.70955 ± 0.00045 (2σ, n = 2). The mean of the three reference samples (dentine and animal bone) from Ordzhonikidze is 0.70985 ± 0.00007 (2σ). A larger variety of reference material was available from Alexandropol'. Three sediment samples, one recent rodent tooth and dentine from three individuals were used to establish a local strontium signature. The samples had a mean $^{87}Sr/^{86}Sr$ ratio of 0.71015 ± 0.00026 (2σ) with a range of 0.70994 to 0.71032.

The geological mixture of Cenozoic sediments, with predicted $^{87}Sr/^{86}Sr$ ratios of 0.709 to 0.711 (Voerkelius et al., 2010), and frequent outcrops of older, partly magmatic, rocks with ratios above 0.711, is not reflected in the reference sample $^{87}Sr/^{86}Sr$ ratios, which seem to be mainly influenced by the Cenozoic sediments.

The five sites in the Northern Pontic region have similar 'local' strontium signatures. This is because of the similarity of the geological bedrock and the close proximity of the sites. If local strontium signatures are calculated for each individual site, a number of enamel $^{87}Sr/^{86}Sr$ ratios lie outside the local range. Two of the Alexandropol' individuals lie below the 'local' strontium range. One of the humans in Babina Mogila is also below the 'local' range, and one of the individuals in Drana Kokhta lies above the 'local' range. The reference samples from Ordzhonikidze form a close cluster, and $^{87}Sr/^{86}Sr$ ratios from four of the individuals lie above the 'local' range. However, the differences in $^{87}Sr/^{86}Sr$ ratios are too small for them to be definitely considered non-local. All but two individuals from Zolotaya Balka lie within the 'local' strontium signature.

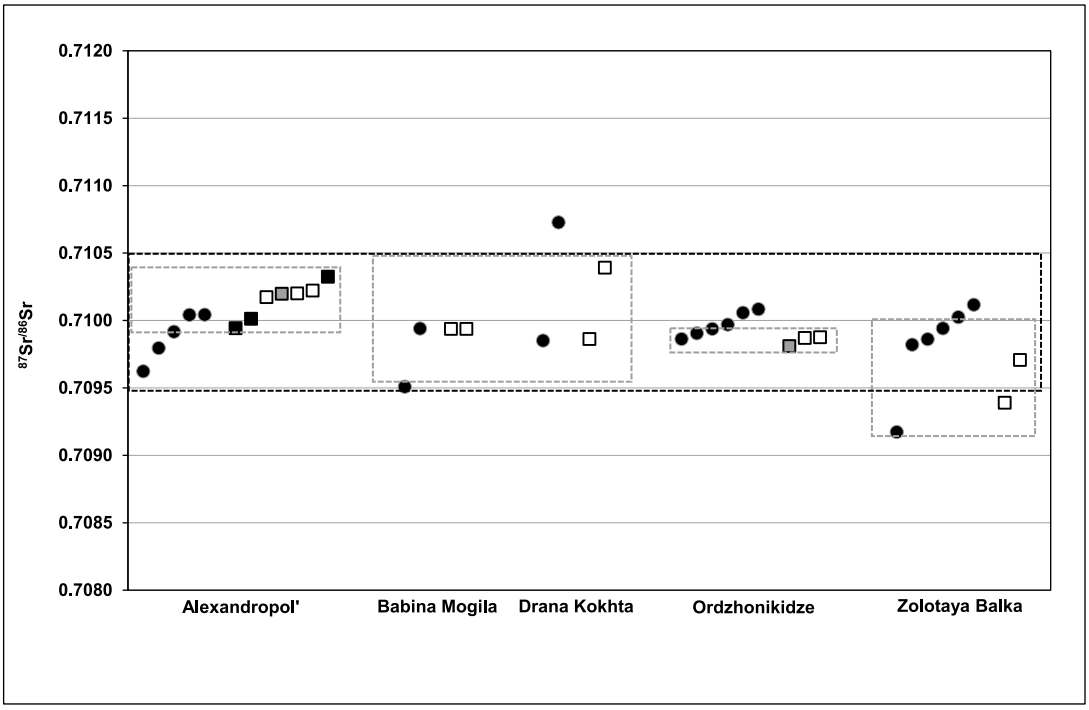


Fig. 4.31 | $^{87}Sr/^{86}Sr$ data for tooth enamel and sampled reference material used to establish the expected 'local' biologically available $^{87}Sr/^{86}Sr$ for the North Pontic sites of the Iron Age Scythian period. Grey rectangles border the 'local' range of each site. Tooth enamel samples are represented by black circles and arranged in a line if belonging to the same individual. Squares represent the reference samples: Sediments (black), faunal samples (grey) and dentine samples (white). Grey rectangles border the local range of each site. The rectangle with the black line represents the overall 'regional' $^{87}Sr/^{86}Sr$ range.

When one amalgamates the reference samples from across the Scythian Northern Pontic, a different patern emerges. In this case, only two samples lie outside the regional strontium signature: kurgan 15, grave 2 in Zolotaya Balka lies below, and niche 5 in Drana Kokhta lies above the range.

Berel' (Kazakhstan) (Fig. 4.32)
One sediment sample, eight human dentine samples and five horse dentine samples were used to calculate the 'local' $^{87}Sr/^{86}Sr$ signature for Berel'. The result is rather complicated because of the unexpectedly wide spread of $^{87}Sr/^{86}Sr$ dentine values. As discussed above, $^{87}Sr/^{86}Sr$ ratios for dentine tend to cluster because dentine is prone to absorb the $^{87}Sr/^{86}Sr$ ratio of the burial environment. In this case, the dentine $^{87}Sr/^{86}Sr$ ratios range between 0.71047 and 0.71218, a span unlikely to represent the 'local' range of biologically available strontium. The mean $^{87}Sr/^{86}Sr$ ratio of all the reference samples is 0.71098 ± 0.00111 (2σ). These results suggest that the dentine samples were only marginally altered by diagenetic processes, if at all, and so the 'local' strontium signature for Berel' cannot be based on the dentine samples. The $^{87}Sr/^{86}Sr$ ratios from the dentine samples from the horses in kurgans 9 and 11 were significantly more radiogenic than the rest of the reference samples so these two samples were excluded from calculations to establish the 'local' strontium signature range. With these the two outliers excluded, the mean $^{87}Sr/^{86}Sr$ ratio is 0.71081 ± 0.00062 (2σ) with a range between 0.71047 and 0.71136.

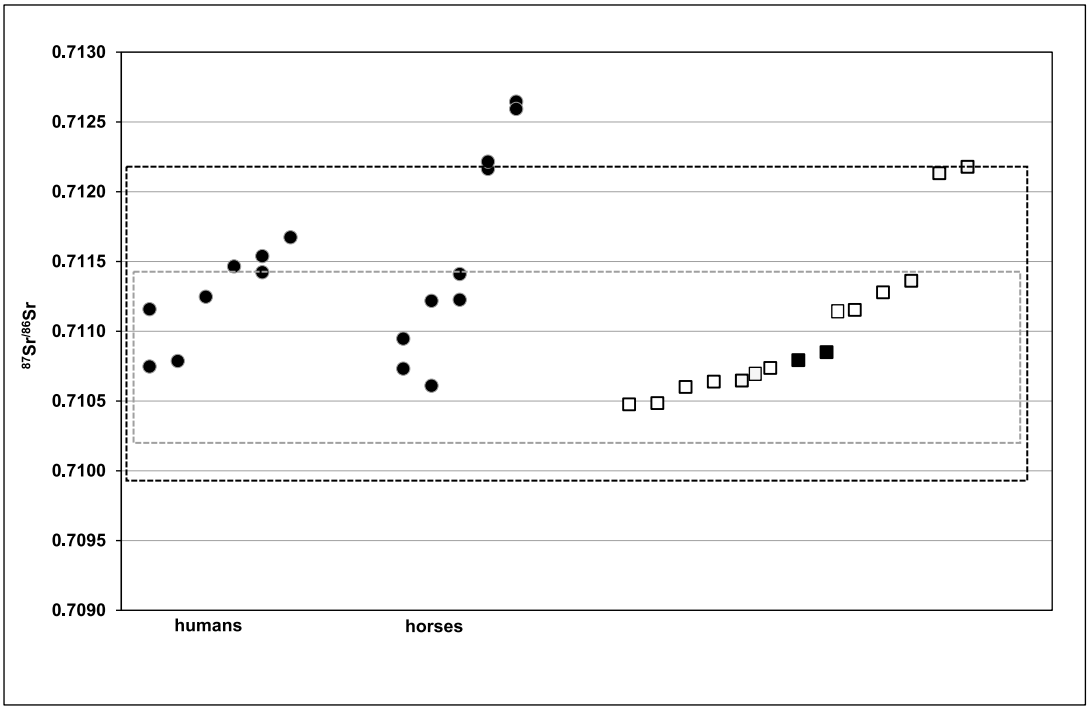


Fig. 4.32 | $^{87}Sr/^{86}Sr$ data for tooth enamel and sampled reference material used to establish the expected 'local' biologically available $^{87}Sr/^{86}Sr$ for Berel'. Tooth enamel samples are represented by black circles and arranged in a line if belonging to the same individual. Squares represent the reference samples: Sediments (black), horse dentine samples (grey) and human dentine samples (white). The large black rectangle shows the 'local' $^{87}Sr/^{86}Sr$ range including all references. The small grey rectangle shows this range excluding the two dentine values from the horses in kurgans 9 and 11.

The Precambrian geology in the Berel' environment points to $^{87}Sr/^{86}Sr$ values above 0.711, which is only partly reflected by the references.

If the 'local' $^{87}Sr/^{86}Sr$ signature is calculated from all of the dentine samples, only two enamel samples lie outside the local range; those from the horses in kurgans 9 and 11 are more radiogenic than the local signature. If the two dentine $^{87}Sr/^{86}Sr$ ratios from these horses are excluded from the calculation to find the local strontium signature, the humans in kurgans 32 (1 tooth), 34 and 72 are also more radiogenic, but variations are very small. As all dentine values, except one from the horse in kurgan 10, are less radiogenic than the enamel from the same individuals, it could be suggested that the burial environment is less radiogenic in this area of the site than in the other parts. One cannot assume that the 'local' strontium signature will be the same as that of the burial environment as the latter is so much more restricted than the wider area which would contribute to a 'local' signature.

4.3.5.3 Evaluation of the 'local' $^{87}Sr/^{86}Sr$ values

The precentages of samples with $^{87}Sr/^{86}Sr$ ratios falling outside the 'local' range are presented in Table 4.3. It is important to emphasize that the validity of percentages is questionable and partly incorrect due to the very small sample sizes. The sites and regions with outlier numbers of less than 20 % are Benkovski and the Hungarian sites (when the references of all sites are combined), Shakhta Stepnaya

and Vinogradnoe, Olennii and, again when the reference samples of all sites are combined, the North Pontic samples of the Scythian period. More than 60% outlier values are present in Smyadovo, Kirovograd, Kalinovka, Politotdel'skoe and Ordzhonikidze. 100% of outlier values are given in Nevskoe, Nikolaevka and Podlesnyi.

In general, there are a high number of samples with $^{87}Sr/^{86}Sr$ ratios falling outside the 'local' strontium rage in Bulgaria and the Volga region compared to the other sites. There seems to be no correlation between sample sizes or the choice of reference samples and percentages of samples falling outside the 'local' signature. Where dentine was the only available material for reference samples, some sites show very low outlier numbers while others show extremely high numbers. There may, however, be a correlation between outlier numbers and the geological variety of a region, for example Bulgaria and the Volga region show larger geological variations than Hungary and the North Pontic.

Table 4.3 | Percentages of outlier $^{87}Sr/^{86}Sr$ ratios of the sample sites and regions.

site	**narrow $^{87}Sr/^{86}Sr$ range (%)**	**wide $^{87}Sr/^{86}Sr$ range (%)**
Eneolithic and Bronze Age		
Benkovski	18	–
Boyanovo	57 ?	–
Ovchartsi	44	–
Smyadovo	50	–
Hungary (total)	17	–
Sárrétudvari	50	–
Kétegyháza	25	–
Kirovograd	79	–
Peshtchanka	14	7/14
Shakhta Stepnaya	–	–
Vinogradnoe	0/4	–
Nevskoe	0/100	–
Olennii	14	–
Sukhaya Termista II	38	–
Volga (total)	53	–
Kalinovka I	67	–
Nikolaevka III	100	–
Politotdel'skoe	66	–
Podlesnyi	100	–
Iron Age Scythian period		
North Pontic (total)	10	–
Alexandropol'	40	–
Babina Mogila, Drana Kokhta	50	–
Ordzhonikidze	50?	–
Zolotaya Balka	33	–
Berel'	43	–

4.4 $\delta^{18}O$ analysis

4.4.1 Basics

4.4.1.1 Introduction

Oxygen has three stable isotopes: ^{16}O, ^{17}O, and ^{18}O with a natural occurrence of 99.76 % (^{16}O), 0.04 % (^{17}O) and 0.2 % (^{18}O) (Faure, 1977, 430; Hoefs, 1987, 37). In tooth and bone, oxygen is bound in the structural carbonate and the phosphate fraction as well as the OH-group of hydroxyl apatite. For oxygen isotope analysis the amount of ^{18}O and ^{16}O, the two most abundant nuclides in a sample, are compared to each other and reported in parts per thousand (‰). The following standard formula is used (Faure/Mensing, 2005, 695):

$$\delta^{18}O\ (‰) = [(^{18}O/^{16}O_{sample} - {}^{18}O/^{16}O_{standard}) / {}^{18}O/^{16}O_{standard}] \times 1000$$

Oxygen isotope ratios are reported against standards. While oxygen ratios in phosphate ($\delta^{18}O_p$) are reported relative to the SMOW (Standard Mean Ocean Water) or V-SMOW (Vienna Standard Mean Ocean Water), oxygen ratios in carbonate ($\delta^{18}O_c$) are reported relative to the PDB (Pee Dee Belemnite) or V-PDB (Vienna Pee Dee Belemnite) standard. The two standards have a linear correlation, which is why through conversion carbonate and phosphate achieve comparable results (Faure, 1977, 431–432; Price et al., 2010, 22). Most studies have used phosphate in tooth enamel or bone (e.g. Luz/Kolodny, 1985; Stuart-Williams/Schwarcz, 1997). Some studies, however, focused on the carbonate in tooth enamel or bone (e.g. Koch et al., 1997), which is less difficult to isolate but more easily diagenetically altered (cf. Katzenberg, 2008, 417 with further literature).

Meteoric water that has fallen from the sky becomes environmental water due to the alteration of the naturally occurring ratio of oxygen isotopes by the hydrology, temperature and seasonality of the environment and includes surface and ground water and is found in rivers, lakes, glaciers and groundwater systems (Longinelli/Nuti, 1973; Luz et al., 1984; Sharp, 2007, 67). By drinking environmental water and to a lesser extent eating plants, the oxygen ratios within it are transferred to the body tissues of animals and humans (Longinelli/Peretti, Padalino, 1980; Longinelli, 1984). Due to this cycle, a clear relationship exists between the $\delta^{18}O$ in body water and that of meteoric water and makes $\delta^{18}O$ a suitable tracer of geographic origin of animals and humans (Longinelli/Nuti, 1973; Luz et al., 1984; D'Angela/Longinelli, 1990). The $\delta^{18}O$ content of meteoric or precipitated water varies widely and systematically across the globe (Bowen et al., 2005, 337) due to differences in temperature, altitude, latitude, and the distance from the sea (Fricke/O'Neil, 1999; Sharp, 2007, 80–86). As the heavier isotope ^{18}O is preferentially precipitated, areas of high rainfall, warmer climates or areas near coasts tend to have enriched $\delta^{18}O$ values and places that the rain reaches later, like mountain ranges or areas further from the source of rain, tend to have depleted values of $\delta^{18}O$. There is a general relationship between oxygen isotope ratios and latitude such that a general depletion of $\delta^{18}O$ values occurs from the south to the north as well as from the west to the east of Europe (Lécolle, 1985; Sharp, 2007, 82–83). This is due to the decrease of heavy $H_2{}^{18}O$ molecules in water vapour with every rain fall and the resulting depletion in $\delta^{18}O$ in rain water. $\delta^{18}O$ in meteoric water additionally varies with the seasons, because fractionation is increased with lower temperatures (Dansgaard, 1964; Sharp, 2007, 82–83). Since $\delta^{18}O$ in precipitation is related to temperature (Gat, 1996), the isotopic composition of rainfall and therefore of drinking water and food

varies between geographic regions and climate zones (Longinelli, 1984; White et al., 2002; Wright et al., 2010). In addition, $\delta^{18}O$ can vary due to differences in diet composition, the amount of water intake and humidity (Dansgaard, 1964; Luz/Kolodny, 1985, 29).

In contrast to strontium, oxygen isotopes belong to the light stable isotope group, which is why major fractionation processes occur. $\delta^{18}O$ in body tissues does not reflect $\delta^{18}O$ in the water that is consumed by humans and animals but is subject to metabolic fractionation and influenced by further oxygen sources like atmospheric oxygen and food (e.g. Longinelli, 1984; Luz et al., 1984; Luz/Kolodny, 1985). In due consideration of metabolic fractionation processes in mammals and the various sources of $\delta^{18}O$ various equations were developed for the analysis of $\delta^{18}O$ in humans and faunal species.

4.4.1.2 Variations in $\delta^{18}O$

4.4.1.2.1 General causes of variations

Among the oxygen-bearing tissues, tooth enamel is one of the best recorders of $\delta^{18}O$. This is due to the strong chemical bonds that oxygen makes in crystalline apatite, the structure of enamel. As tooth enamel does not undergo remodelling after its formation (Bryant et al., 1996b, 397; Kohn et al., 1998, 97), it reflects the oxygen signal of childhood. Dentine and bone, in contrast, contain less apatite and smaller crystallites (Kohn et al., 1996, 3892) and are constantly renewed during the lifetime of the individual.

The direct comparison of $\delta^{18}O$ in fossil teeth with that in modern precipitation offers pitfalls. Firstly, the $\delta^{18}O$ of precipitation does not necessarily equal the $\delta^{18}O$ in the surface water that supplied the main sources of drinking water in prehistoric times (Daux et al., 2008, 1146). This is because drinking water is composed not only of precipitation, but also of groundwater that may have been stored in the rocks for a considerable length of time and isotopically altered over that time. Another source contributing to drinking water can be melting glaciers, which again may have a different proportion of ^{18}O to that of the local precipitation. Where drinking water came from distantly sourced rivers or glacial melt streams, the ratios cannot be compared to local meteoric precipitation (White et al., 1998, 645). Daux et al. (2008) found that rivers that are fed by mountain lakes or originate in higher altitudes deviate by 1.6 to 1.9 ‰ from the OIPC, the Online Isotopes in Precipitation Calculator, values (Daux et al., 2008, 1141, table 1). Secondly, modern $\delta^{18}O$ in precipitation and palaeoclimate $\delta^{18}O$ in precipitation are not always equivalent (Dansgaard, 1964). Furthermore, climate oscillations in prehistory lead to variations in $\delta^{18}O$ values. Calculations of the $\delta^{18}O$ values for the areas between the Global Network of Isotopes in Precipitation (GNIP) stations found that in general, $\delta^{18}O$ in precipitation depends on the following variables: latitude, distance from the ocean, altitude and temperature.

The 'latitude effect' describes the decrease of $\delta^{18}O$ in precipitation with increasing latitude, which is due to the increase of the degree of 'rainout' of air masses as temperatures decrease with latitude. This decrease in $\delta^{18}O$ is regular but not linear. In mid-latitude regions the gross magnitude of the latitude effect is approximately –0.5 ‰ per degree of latitude (Sharp, 2007, 83). Fricke and Neil (1999) published a gradient of approximately –0.6 ‰ for each degree of latitude, and Lécolle (1985, 174) found a gradient of –2.1 ‰ for each 1000 km in his study on land snails in Europe.

$\delta^{18}O$ in precipitation also decreases with increasing distance from the ocean, which is described as the 'continentality effect'. ^{18}O leaves the system with each rain shower and hence leads to a decreased

proportion of ^{18}O and an increased proportion of ^{16}O. For each 1000 km, $\delta^{18}O$ in precipitation decreases by about 1.5 ‰ in summer and 3 ‰ in winter (Sharp, 2007, 83).

Another known effect is the 'altitude effect'. Förstel and Hützen (1983) specify the adjustments in altitude to range from –0.3 ‰ to –0.44 ‰ per 100 m. For Italy, Longinelli and colleagues (2006) found an altitude gradient of –0.2 ‰/100 m. For most places in the world and for elevations of up to 5000 m there is a characteristic gradient of –0.26 ‰/100 m based on a compilation of data from 68 studies by Poage and Chamberlain (Poage/Chamberlain, 2001).

Furthermore, $\delta^{18}O$ in precipitation is correlated with temperature. Rozanski et al. (1993) give the relationship of ^{18}O in precipitation with varying temperature as 0.6 ‰ per °C.

4.4.1.2.2 Seasonal variation

Seasonal changes in $\delta^{18}O$ in precipitation are caused by seasonal variations in temperature, humidity and precipitation (Kohn, 1996, 4822) and are evidenced by higher $\delta^{18}O$ values in the warmer season and lower values in the colder months (Dansgaard, 1964). This creates an annual cycle similar to a cosine wave for precipitation and this translates into body tissues (Bryant et al., 1996a, 82). These intra-annual variations have been demonstrated in several studies (e.g. Bryant et al., 1994; Bryant et al., 1996a). The annual variability of rainfall levels has a significant influence on the intra-site range of $\delta^{18}O$ values (Price et al., 2010, 22). Sinusoidal waves in intra-tooth or intra-jaw $\delta^{18}O$ are observed in studies at high or mid latitudes, in low latitudes as the tropical areas or in regions of low rainfall these patterns are usually not visible (Britton et al., 2009, 1165). Longinelli (unpublished data; 1983) found that a change in the $\delta^{18}O$ of body water in relation to alternations in the isotopic composition of local meteoric water occurs only after several weeks or months (D'Angela/Longinelli, 1990, 77).

Due to temporal differences in tooth eruption and period of mineralization, a continuous record of $\delta^{18}O$ changes is provided. A vertical section taken from the tooth enamel in animals represents the average $\delta^{18}O$ over approximately a year when sampled as a whole (Brown et al., 1960). Sequential sampling of the vertical tooth section, on the other hand, provides information on seasonal changes. Bryant et al. (1996a) and Fricke and O'Neil (1996) found huge intra-tooth changes in equids, sheep and bison, for example. More recent studies include the analysis of *Linearbandkeramik* cattle in southwest Germany (Knipper, 2011), intra-tooth differences in sheep tooth enamel due to seasonal dietary changes (Balasse et al., 2006) and vertical transhumance studies on modern sheep/goat in the Zagros Mountains (Mashkour, 2003). As mentioned above, seasonal changes in temperature, rainfall and humidity affect the $\delta^{18}O$ in drinking water and are therefore tracers for seasonality (Kohn et al., 1998, 97). Additionally, dietary changes occurring during enamel mineralization are reflected in the $\delta^{18}O$ locked into the enamel. Intra-annual variations in $\delta^{18}O$ that occurred during the formation of tooth enamel, which takes up to three years in the third molars of horses for example (Bryant et al., 1996a; Bryant et al., 1996b; Higgins/MacFadden, 2004), are detected by sequential sampling of tooth enamel either by conventional TIMS method or by laser ablation MC-ICP-MS. In cases where the mineralization period of a tooth does not include a whole annual cycle, the $\delta^{18}O$ value of the tooth enamel will not represent an annual average. The enamel $\delta^{18}O$ value of young animals that were born in late winter or spring and were killed by the end of summer or early autumn is slightly more enriched than the yearly mean $\delta^{18}O$ value of meteoric water because the months with higher temperatures are included whereas month with lower temperatures are not included (D'Angela/Longinelli, 1990, 81).

Intra-annual variations in $\delta^{18}O$ are influenced by several factors, the 'dampening-effect' and the 'amount-effect'. The climate of the steppe area is characterized by hot and dry summers with highly evaporative conditions and cold winters with high precipitation falling as rain and snow. If herding animals and their herders had movement patterns from cooler areas in summer to warmer areas in winter, for example between mountains and lowlands, the expected $\delta^{18}O$ differences between summer and winter would be mediated (Bryant et al., 1996b, 404). If individuals stayed in one place year-round, on the other hand, variations in $\delta^{18}O$ in tooth enamel would be more visible. $\delta^{18}O$ also varies with the amount of precipitation in areas of pronounced dry and wet periods (the 'amount-effect'). In wet periods $\delta^{18}O$ in precipitation is enriched, while in dry periods $\delta^{18}O$ in precipitation is depleted (Higgins/MacFadden, 2004, 338; Sharp, 2005, 83–84).

4.4.1.2.3 Intra-tooth and intra-species variation

Due to incremental tooth mineralization from crown to root, intra-tooth and intra-species $\delta^{18}O$ variations occur. For most animal species there are uncertainties in the timing of initial enamel mineralization and the duration period (Kohn et al., 1998, 102). For different animal genera, $\delta^{18}O$ differences within single teeth and between teeth from a single jaw have been shown in equids and sheep (e.g. Balasse et al., 2002; Bryant et al., 1996 a, b). In addition, equids have hypsodont (high-crowned) teeth, in which the isotopic composition of several months to years is recorded (Higgins/MacFadden, 2004, 342). Kohn et al. (1998) found isotope heterogeneity within sets of teeth of different animals (zebra, gazelle) of ~ 2 ‰, as well as within individual teeth (Kohn et al., 1998, 97). Kohn et al. (1996, 3893) found inter-tooth differences of up to 3 ‰, which they explain through variability in animal diet and physiology.

4.4.1.2.4 Intra-site variation

There are significant variations between populations with the same water and food supply. Some studies show that there is only a limited variation of ~ 1 ‰, in wild species and humans (Longinelli, 1984; White et al., 1998; White et al., 2000), whereas others show a much larger range of variation (Luz et al., 1990; Stuart-Williams/Schwarcz, 1997). Variations of up to 2 ‰ for humans were reported from a single location (White et al., 2004b). Reported variations for animals are about 2.4 ‰ for horses (Bryant et al., 1996b), 2.2 ‰ for cattle (D'Angela/Longinelli, 1990), 2.1 ‰ for kangaroos (Ayliffe/Chivas, 1990), and 0.7 ‰ for deer (Luz et al., 1990).

One explanation for intra-site scattering in $\delta^{18}O$ values could be differences in food supply (D'Angela/Longinelli, 1990, 79). Animals obtaining their water intake mainly from food show $\delta^{18}O$ compositions that are closely related to humidity, while animals with high water turnovers have $\delta^{18}O$ compositions closely related to surface water compositions (e.g. antelopes versus goats; Kohn et al., 1996, 3895). Water sources offer potential uncertainties. Humans and animals from the same site might have different water supplies. At some sites, for example in the Altai Mountains, glacier water and snow melt contribute to influence the river water in mountain valleys. Consequently, water from larger mountain streams can be isotopically different (and often more depleted as snow melt and glacier water originate from mountain peaks) than small rivers and springs (Müller et al., 2003, 863). The oxygen iso-

topic values of humans and animals analysed in the study of D'Angela/Longinelli (1993) were in accord with the $\delta^{18}O$ in water sources of the nearby mountains rather than the estimated local ones (D'Angela/Longinelli, 1993, 176–177). In the study of Iacumin et al. (2004a) animals showed more elevated $\delta^{18}O$ values than humans, which was probably caused by differences in water sources. One explanation could be that river water, which is normally more negative than local rain water, was drunk by the humans. A second reason could be that a significant proportion of water uptake in herbivores comes through grass water, where high rates of evapotranspiration cause an ^{18}O enrichment of grass and leaf water (Iacumin et al., 2004a, 172). Water in fruits can also be enriched over soil water taken up by their roots (Wright/Schwarcz, 1998, 14). Sponheimer/Lee-Thorp (1999, 724) and this could explain why herbivores are enriched in ^{18}O compared to carnivores. The extended boiling of beverages can likewise lead to ^{18}O enrichment (Wright/Schwarcz, 1998, 14). Variations in $\delta^{18}O_{phosphate}$ in tooth enamel of up to 1.1 ‰ in comparison to $\delta^{18}O$ in meteoric water were explained by the cooking of food (Daux et al., 2008). Another source of uncertainty is C_3 and C_4 plants. The $\delta^{18}O$ in the cellulose of C_3 plants is lower than in C_4 plants, because C_4 plants are heat and light adapted and continue photosynthesizing in dry conditions. This leads to enrichment in plant cellulose and leaf water. In dry regions, variations of up to 10 ‰ can be found between C_3 and C_4 plants (White et al., 2004b, 234). Finally, a sequence of years with temperatures below or above average influences the $\delta^{18}O$ in tooth enamel during the mineralization period.

Another explanation for intra-site scattering in $\delta^{18}O$ could be breastfeeding and weaning, which are thought to alter the $\delta^{18}O$ signal in tooth enamel to an unknown degree. Mother's milk is enriched in $\delta^{18}O$ up to 2.69 ‰ (Katzenberg, 2008, 430). Due to the fact that their main source of water is mother's milk, breastfeeding infants are one trophic level above their mothers. This is why there is an enrichment of up to 0.7 to 1 ‰ in enamel that mineralizes in very early childhood (White et al., 2004a, 393; Wright/Schwarcz, 1998, 1; Eckardt et al., 2009, 2819). Enrichment in ^{18}O due to breastfeeding was attested for the human skeletons in Teotihuacan (e.g. White et al., 2000; 2004b), as well as for fauna such as horses (Bryant et al., 1996) and sheep (Fricke/O'Neil, 1996). Schulz, on the other hand, could neither postulate a significant difference between first and second molars, nor did he find any indicators for the exact point of weaning (Schulz, 2006, cited in Vohberger, 2011, 175–176).

The $\delta^{18}O$ signal in premolars and first molars is similar and presents an altered $\delta^{18}O$ signal due to the $\delta^{18}O$ enrichment in mother's breast milk. Third molars are depleted by up to 0.5 ‰ compared to premolars and by 0.7 ‰ compared to first molars (Wright/Schwarcz, 1998, 1). According to the study of Wright and Schwarcz (1998, 15), weaning occurred at about 5 to 6 years of age. Hence, there should be no effect from breastfeeding in the $\delta^{18}O$ signal from the third molars in humans (Kohn et al., 1998, 102). Wright and Schwarcz (1998) showed that while $\delta^{18}O$ decreases, $\delta^{13}C$ increases with age, which they explain by the stepwise transition from breastfeeding to solid food.

Bryant et al. (1994) found that foals before weaning adapt the isotopic signal of mares rather than that of the surface water and are therefore approximately –4 ‰ off the expected isotope values. This is caused by the isotope fractionation of drinking water to body water in the mare (Bryant et al., 1994; Luz et al., 1984). The influence of mare's milk, which gradually decreases, is seen in the first and second molars of the foals. Third molars P2 to P4 on the other hand mineralize mainly after weaning and therefore show no influence from the mother's milk (Bryant et al., 1996b, 402).

4.4.1.3 $\delta^{18}O$ analysis of $\delta^{18}O$ in tooth enamel carbonate

Most studies of archaeological material are based on $\delta^{18}O$ analysis in phosphate ($\delta^{18}O_{phosphate} = \delta^{18}O_p$) which is due to stronger chemical bonds between phosphate and oxygen than carbonate and oxygen. Lee-Thorp and van der Merwe (1991) and Wang and Cerling (1994) showed that oxygen in bone phosphate is less susceptible to diagenetic alteration, while structural carbonate is considered more susceptible. The weaker bonds of oxygen-carbonates and the consequent greater likelihood of post depositional substitution of oxygen in bone are not a factor in tooth enamel analysis (Iacumin et al., 1996). As tooth enamel is less organic and highly crystalline, and therefore less prone to diagenetic alteration, several studies are based on the measurement of $\delta^{18}O_{carbonate}$ ($\delta^{18}O_c$) in this tissue (e.g. Sponheimer/Lee-Thorp, 1999, 724; Lee-Thorp/van der Merwe, 1991; Wright/Schwarcz, 1998).

4.4.1.4 Data conversion

4.4.1.4.1 Conversion of $\delta^{18}O_c$ measured relative to V-PDB into V-SMOW

To enable the comparison of the data obtained by other studies, the $\delta^{18}O_c$ needs to be converted. The existence of a strong correlation between $\delta^{18}O_c$ and $\delta^{18}O_p$ has been shown in several studies (Iacumin et al., 1996; Bryant et al., 1996; Chenery et al., 2012). The advantage of the analysis of $\delta^{18}O_c$ in teeth in comparison to $\delta^{18}O_c$ and $\delta^{18}O_p$ in bone is its better preservation (Price et al., 2010, 22).

As a first step, data obtained as $\delta^{18}O_c$ and measured against the PDB (Pee Dee Belemnite) standard needs to be converted into data expressed against SMOW (Standard Mean Ocean Water), to which phosphate is commonly referred (Hoefs, 1987, 40). For the conversion of data from $\delta^{18}O_c$ (V-PDB) into $\delta^{18}O_c$ (V-SMOW) several conversion equations can be adapted, most commonly this is the equation by Coplen et al. (1983) (cf. also Coplen, 1988, equation 11):

$$\mathbf{\delta^{18}O_c\ (V\text{-}SMOW) = 1.03091 \times \delta^{18}O_c\ (V\text{-}PDB) + 30.91}$$

As a second step, data expressed as $\delta^{18}O_c$ (V-SMOW) needs to be converted into $\delta^{18}O_p$ (V-SMOW). Iacumin et al. (1996) analysed 31 tooth and bone samples from modern mammals from different climatic regions for oxygen isotopic composition of phosphate and structural carbonate of hydroxyl apatite and found an approximate mean difference of 9.2 ‰ between carbonate and phosphate data. They established the following, commonly applied equation to convert $\delta^{18}O_c$ into $\delta^{18}O_p$, both measured against V-SMOW:

$$\mathbf{\delta^{18}O_p\ (V\text{-}SMOW) = 0.98 \times \delta^{18}O_c\ (V\text{-}SMOW) - 8.5}$$

A recent study on the relationship between $\delta^{18}O_c$ and $\delta^{18}O_p$ based on 51 archaeological tooth enamel samples was published by Chenery et al. (2012), where the authors established the following equation: $\mathbf{\delta^{18}O_p = 1.032 \times \delta^{18}O_c - 9.6849\ (r^2 = 0.98)}$.

4.4.1.4.2 Conversion into data comparable to meteoric water

Mammals have a constant body temperature of 37 ± 2 °C. Due to this the temperature-dependent fractionation of oxygen isotopes, the composition of the phosphate fraction of bone and tooth is controlled by the oxygen isotope composition of the body water (White et al., 1998, 645). Consequently, $\delta^{18}O$ in tooth and bone in mammals is strongly correlated to the oxygen isotopic composition of ingested water (Bryant et al., 1994, 303). The $\delta^{18}O$ in body water and consequently the $\delta^{18}O$ in phosphate are controlled by the balance of oxygen inputs and outputs. Besides oxygen inputs and outputs, body mass is another factor of influence (Bryant et al., 1996a, 77; White et al., 1998, 645) as fractionation processes cause variations between atmospheric oxygen and inhaled oxygen. Kohn (1996, 4813) names two important issues concerning oxygen input: the first is that $\delta^{18}O$ of surface water and plants are more or less equal, and the second is that $\delta^{18}O$ of surface/drinking water equals $0.69 \times T$ (°C) – 13.6 (Dansgaard, 1964). Oxygen inputs are drinking water, water in food, air oxygen and air water vapour (Bryant et al., 1996a, 77). Oxygen body outputs are CO_2, respiratory H_2O vapour, sweat, urine and fecal water.

The linear relationship between $\delta^{18}O$ in body water and $\delta^{18}O$ in meteoric water needs to be calibrated. The fractionation between $\delta^{18}O_p$ and $\delta^{18}O$ in body water is linked with body size and the metabolic changes in the mammal. Generally speaking, the gradient between $\delta^{18}O_p$ and $\delta^{18}O$ in body water increases with increasing body size (Bryant et al., 1994, 312). Different models were developed to provide a basis of comparison. Kohn (Kohn, 1996, 4812) distinguishes between three types of models: general models (e.g. Luz/Kolodny, 1985; Luz et al., 1990; Ayliffe/Chivas, 1990), genus-specific models and hybrid models, which were generalized after being developed for specific animal genera (e.g. Bryant/Froelich, 1995).

In 1966 Lifson and McClintock developed a mass balance model for the isotopic composition of body water (Bryant/Froelich, 1995, 4523). Longinelli (1984) and Luz et al. (1984) were the first to recognize that empirically derived equations were valid for the studied species only and that these equations cannot be used interspecifically. In the following years and decades different authors developed a number of mass-dependent models. The equations that are offered in the models show large interspecific variation in the gradients and intercepts (Bryant/Froelich, 1995, 4523 table 1).

The importance of animal physiology per species versus climate indicators is unknown and the impact of local climate versus physiology is debated (e.g. studies of Longinelli, 1984; Luz et al., 1984; D'Angela/Longinelli, 1990; Ayliffe/Chivas, 1990; Luz et al., 1990; Delgado Huertas et al., 1995). In further studies it was shown that animal genera play an important role (Kohn, 1996). For animals with a constant body temperature, oxygen input and output determine the $\delta^{18}O$ values. Quantities of input and output depend on different variables: species-size, water dependency, water conservation ability, and metabolic rate (White et al., 2004b, 234).

A sophisticated model taking seasonal signals (water composition, temperature, and humidity), physiology and diet into account, is difficult to define on a general basis that can be applied in different regions. Therefore, more generalized models, though not particularly precise, may be applied in other regions and on similar animal species.

Human equations

The different conversion steps are shown in Table 4.4. After carbonate data is converted from $\delta^{18}O_c$ (V-PDB) to $\delta^{18}O_c$ (V-SMOW) as a first step (Coplen et al., 1983) and then the subsequent $\delta^{18}O_c$ (V-SMOW) converted to $\delta^{18}O_p$ (V-SMOW) (Iacumin et al., 1996), the $\delta^{18}O_p$ is compared to $\delta^{18}O$ of water

Table 4.4 | Oxygen isotope fractionation equations used for conversion of $\delta^{18}O_c$ into $\delta^{18}O_w$ for humans.

author	equation
1 carbonate V-PDB to V-SMOW	
Coplen et al., 1983	$\delta^{18}O_{carbonate}$ (V-SMOW) = 1.03091 × $\delta^{18}O_{carbonate}$ (V-PDB) + 30.91
2 carbonate to phosphate V-SMOW	
Iacumin et al., 1996	$\delta^{18}O_{phosphate} = 0.98 \times \delta^{18}O_{carbonate} - 8.5$
3 to drinking water	
Longinelli, 1984 (as in Daux et al., 2008)	$\delta^{18}O_{water} = 1.53 \times \delta^{18}O_{phosphate} - 34.3$
Luz et al., 1984 (as in Daux et al., 2008)	$\delta^{18}O_{water} = 1.2 \times \delta^{18}O_{phosphate} - 27.42$
Levinson et al., 1987 (as in Daux et al., 2008)	$\delta^{18}O_{water} = 1.93 \times \delta^{18}O_{phosphate} - 38.51$
Daux et al., 2008	$\delta^{18}O_{water} = 1.54 \times \delta^{18}O_{phosphate} - 33.72$
Pollard et al., 2011	$\delta^{18}O_{water} = 1.55 \times \delta^{18}O_{phosphate}$ (V-SMOW) − 33.49
Chenery et al., 2012 (on Daux et al., 2008, equation 6)	$\delta^{18}O_{water} = 1.59 \times \delta^{18}O_{carbonate}$ (V-SMOW) − 48.634

(but cf. critics in Pollard et al., 2011a). However, calculations of drinking water $\delta^{18}O$ values from tooth enamel may vary subject to the equation despite the linear relationship between drinking water and human body tissue (Daux et al., 2008; Pollard et al., 2011a). Pollard and colleagues (2011a) found the uncertainty within drinking water equations to lead to errors on the calculated $\delta^{18}O_w$ values between ± 1 ‰ and ± 3.5 ‰. The main equations for humans used in recent literature are Longinelli, 1984, Luz et al., 1984; Levinson et al., 1987; Daux et al., 2008; Pollard et al., 2011a and Chenery et al., 2012.

In 1984 Longinelli was the first to publish a dataset, in which the existence of a quantitative, direct relationship between the mean oxygen isotopic composition of local meteoric water and the oxygen isotopic composition of bone phosphate was shown and he developed an equation for humans ($\delta^{18}O_w = 1.53 \times \delta^{18}O_p - 34.30$; $r^2 = 0.97$, $n = 10$) and domestic pigs (Longinelli, 1984). Another species specific model was created by Luz and colleagues, also in 1984, where $\delta^{18}O_w = 1.19 \times \delta^{18}O_p - 27.42$ ($r^2 = 0.95$, $n = 6$). In their study on oxygen isotopic compositions of human teeth and urinary stones Levinson et al. (1987) found that the best fit linear regression yielded $\delta^{18}O_w = 1.93 \times \delta^{18}O_p - 38.51$ ($r^2 = 0.92$, $n = 14$) (see also Daux et al., 2008, table 2).

The three researchers named above consider humans as medium-sized mammals with moderate water turnovers and take into account that humans, as omnivores, take up less water from food than do herbivores. Daux and colleagues refined the human fractionation equation for the conversion of $\delta^{18}O_p$ into $\delta^{18}O_w$. Daux et al. (2008) present a regression equation that was set up on the basis of the analysis of $\delta^{18}O_p$ of human tooth enamel for humans with a similar nutrition as today. A single classification 'Analysis of Covariance' indicated a difference of the four models at $\alpha = 0.01$ significance level (Daux et al., 2008, 1143). In consequence, they consider the four linear models calculated as random estimates of a unique $\delta^{18}O_w$/ $\delta^{18}O_p$ linear relation and they therefore combine the samples into a large set of 42 samples. On the basis of this data set they developed their overall model with reduced uncertainties and more accurate predictions (Daux et al., 2008, 1144). After testing the three previously published equations for humans of Longinelli (1984), Luz et al. (1984) and Levinson et al. (1987), Daux et al. found that even if they are linear, they differ in their intercepts as well as in their gradients. Therefore, they developed the following linear equation:

$\boldsymbol{\delta^{18}O_w = 1.54 \times \delta^{18}O_p - 33.72\ (r^2 = 0.87,\ n = 42).}$

Another linear equation based on a 'superset' of 94 samples (a compilation of the data published by Longinelli, 1984, Luz et al., 1984, Levinson et al., 1987, Daux et al., 2008 and new data) was developed by Pollard and colleagues (2011a):

$\boldsymbol{\delta^{18}O_w = 1.55 \times \delta^{18}O_p - 33.49\ (r^2 = 0.91,\ n = 94).}$

Chenery et al. (2012) published an equation that allows the direct calculation of drinking water values from structural carbonate data. The authors refer to data that was normalised to the PDB scale and then converted into the SMOW scale using the following published conversion equation by Coplen (1988, equation 11): $\boldsymbol{\delta^{18}O_c}$ **(V-SMOW) = 1.03091 ×** $\boldsymbol{\delta^{18}O_c}$ **(V-PDB) + 30.91**. They established a direct relationship between $\delta^{18}O_c$ and $\delta^{18}O_p$ values from human tooth enamel: $\boldsymbol{\delta^{18}O_p}$ **(V-SMOW) = 1.0322 ×** $\boldsymbol{\delta^{18}O_c}$ **(V-SMOW) – 9.6849 (r^2 = 0.98, n = 51)**. This conversion equation was subsequently combined with the published drinking water conversion equation of Daux and colleagues (2008, equation 6), allowing direct calculation of $\delta^{18}O$ in drinking water from $\delta^{18}O$ in the carbonate fraction of human bioapatite relative to V-SMOW. This resulted in the following equation:

$\boldsymbol{\delta^{18}O_w = 1.590 \times \delta^{18}O_c}$ **(V-SMOW) – 48.634.**

The authors provide a second option for data conversion based on equation 4 in Daux et al. (2008): $\boldsymbol{\delta^{18}O_w = 1.786 \times \delta^{18}O_c}$ **(V-SMOW) – 54.005**.

Faunal equations

Linear regression lines with respect to the relationship between $\delta^{18}O$ in body tissue and $\delta^{18}O$ in water were not only calculated for humans but also for a large variety of animal species (Table 4.5). The first to find that there was a simple linear relationship between bone phosphate, body water and local meteoric water for certain faunal species were Longinelli (1984) for domestic pigs and Luz and Kolodny (1985) for rats. Five years later D'Angela and Longinelli (1990) published equations for deer, cattle, sheep and wood mice, some of them were later revised (Longinelli et al., 2003). Equations for further faunal species followed over the 1990s. Horses and wild horses were the focus of several studies, which lead to a number of very similar equations by Sànchez Chillón et al. (1994), Bryant et al. (1994) and Delgado Huertas et al. (1995).

Apart from the species specific models, a generalized mass-dependant model has been developed by Bryant and Froelich (1995). Kohn et al. (1996) found that reasons apart from body size, which were not considered by Bryant and Froelich (1995), were responsible for the variations observed in their study. Kohn et al. (1996) assume animals with low water turnover rates to have higher $\delta^{18}O$ ratios due to less isotopically enriched food and less isotopically depleted lake water uptake. They also expect C_4 plant consumers to have higher $\delta^{18}O$.

In his generalized genus-specific model, Kohn (1996) incorporated the prediction of animal body water and phosphate $\delta^{18}O$. He emphasized the importance of animal physiology versus climate as $\delta^{18}O$ in tooth enamel can vary significantly depending on animal species even in similar climatic conditions (Kohn et al., 1996; Kohn, 1996, 4811).

According to Kohn (1996, 4817), several factors can explain differences in models and data such as the fact that $\delta^{18}O$ in local water may have been more enriched during seasonal bone growth (Luz et al.,

Table 4.5 | Conversion equations of $\delta^{18}O_w$ to $\delta^{18}O_p$ for selected faunal species.

animal species	**author**	**equation**
domestic pigs	Longinelli, 1984	$\delta^{18}O_p = 0.86 \times \delta^{18}O_w + 22.71$
rats	Luz et al., 1984	$\delta^{18}O_p = 0.59 \times \delta^{18}O_w + 0.24$
micromammals (wood mice)	D'Angela/Longinelli, 1990	$\delta^{18}O_p = 0.79 \times \delta^{18}O_w + 21.61$
micromammals	Longinelli et al., 2003 (D'Angela/Longinelli, 1990 revised)	$\delta^{18}O_p = 1.07 \times \delta^{18}O_w + 22.72$
elephants	Ayliffe et al., 1992	$\delta^{18}O_p = 1.06 \times \delta^{18}O_w + 24.3$
cattle	D'Angela/Longinelli, 1990	$\delta^{18}O_p = 1.01 \times \delta^{18}O_w + 24.90$
cattle (Europe)	D'Angela/Longinelli, 1990	$\delta^{18}O_p = 0.80 \times \delta^{18}O_w + 21.79$
	Hoppe, 2006	$\delta^{18}O_p = 0.82 \times \delta^{18}O_w + 21.79$
deer	D'Angela/Longinelli, 1990	$\delta^{18}O_p = 1.13 \times \delta^{18}O_w + 25.55$
deer	Iacumin et al., 1996b	$\delta^{18}O_c = 0.998 \times \delta^{18}O_w + 33.63$
reindeer	Longinelli et al., 2003 (Iacumin/Longinelli, 2002 revised)	$\delta^{18}O_p = 0.44 \times \delta^{18}O_w + 16.82$
sheep	D'Angela/Longinelli, 1990	$\delta^{18}O_p = 1.48 \times \delta^{18}O_w + 27.21$
goats, roe-bucks	Delgado Huertas et al., 1995	$\delta^{18}O_p = 0.88 \times \delta^{18}O_w + 24.1$ (revised from $\delta^{18}O_p = 0.91 \times \delta^{18}O_w + 24.39$)
horses	Sánchez Chillón et al., 1994	$\delta^{18}O_p = 0.73 \times \delta^{18}O_w + 22.04$
horses	Bryant et al., 1994	$\delta^{18}O_p = 0.69 \times \delta^{18}O_w + 22.90$
horses	Delgado Huertas et al., 1995	$\delta^{18}O_p = 0.72 \times \delta^{18}O_w + 22.29$
wild horses	Delgado Huertas et al., 1995	$\delta^{18}O_p = 0.71 \times \delta^{18}O_w + 22.60$

1990), or that the composition of rain water may be different to drinking water (Ayliffe et al., 1992), and to differences in humidity (Ayliffe/Chivas, 1990; Luz et al., 1990).

4.4.1.5 Data comparison

4.4.1.5.1 Comparison to $\delta^{18}O$ results of studies in the same region

The best basis for comparison would undoubtedly be $\delta^{18}O$ values from settled prehistoric humans living in the same study region. Faunal material can also serve as comparison material with certain reservations. In the study area, however, only single studies were conducted (Iacumin et al., 2004a; 2004b, Keenleyside et al., 2011), the results of which are shown in chapter 4.4.5.2.

Table 4.6 | Altitude, air temperature, annual precipitation and $\delta^{18}O$ mean values recorded at GNIP stations in the study area. IAEA/WMO (2006). Global Network of Isotopes in Precipitation: The GNIP Database. Accessible at: http://www.iaea.org/water (last accessed 10. 08. 11).

GNIP station	altitude (m)	temperature mean (°C)	precipitation (mm)	$\delta^{18}O$ mean (‰)	weighted $\delta^{18}O$ mean (‰)
Odessa (Ukraine)	64	9.4	350	–9.00	–9.07
Rostov (Russia)	77	8.7	506	–8.56	–8.10
Saratov (Russia)	166	6.8	462	–11.78	–10.94
Astrakhan (Russia)	–18	10.6	221	–7.51	–7.87

4.4.1.5.2 Comparison to $\delta^{18}O$ in modern precipitation

The calculated $\delta^{18}O_w$ values can be compared to $\delta^{18}O$ in precipitation, although there is a significant level of uncertainty due to different $\delta^{18}O$ drinking water sources (cf. Chapter 4.4.1.2). The $\delta^{18}O_w$ values can be compared with data published on the International Atomic Energy Agency (IAEA) website (see the weighted mean $\delta^{18}O$ in precipitation), or with the Online Isotopes in Precipitation Calculator (OIPC) (Bowen/Wilkinson, 2002; Bowen/Revenaugh, 2003; Bowen et al., 2005; Bowen, 2010). The IAEA and the WMO (World Meteorological Organisation) published a database of a global network of isotopes in precipitation (GNIP), which is accessible at http://www.iaea.org/water. Worldwide monthly precipitation samples have been taken from more than 800 meteorological stations since 1961. The samples were analysed for oxygen, deuterium and tritium at various laboratories, but mostly at the IAEA Laboratory in Vienna, Austria. There are only four GNIP stations in the study area, where $\delta^{18}O$ data was gathered: Odessa in Ukraine, and Rostov, Saratov and Astrakhan in Russia (Table 4.6). Equal weighted mean $\delta^{18}O$ are gathered from the two sites at the Black Sea Coast, Odessa and Rostov. Astrakhan, being further to the east but in a more arid region yields an approximately 1.5 ‰ less depleted weighted mean $\delta^{18}O$. Saratov, situated half way between Volgograd and Samara at the River Volga, yields a much more depleted weighted mean $\delta^{18}O$.

The map with weighted $\delta^{18}O$ means at GNIP stations and long-term annual average $\delta^{18}O$ data (Fig. 4.33) shows that there is a gradient from south to northeast with less depleted oxygen isotope ratios in modern Bulgaria and most depleted values in the middle Volga region.

Alternatively, one can compare data deriving from the OIPC (http://wateriso.utah.edu/waterisotopes/pages/data_access/oipc.html) (Fig. 4.34). The $\delta^{18}O$ data on this website yields a good match, even though the values present the oxygen isotope ratios in modern precipitation. Daux et al. (2008, 1142) found a generally good relationship between the OIPC values ($\delta^{18}O$ in precipitation) and $\delta^{18}O$ in tap water that did not exceed 0.8 ‰. The trend of less depleted $\delta^{18}O$ values in the southwest and most depleted $\delta^{18}O$ values in the northeast of the study area is also apparent on the basis of this data.

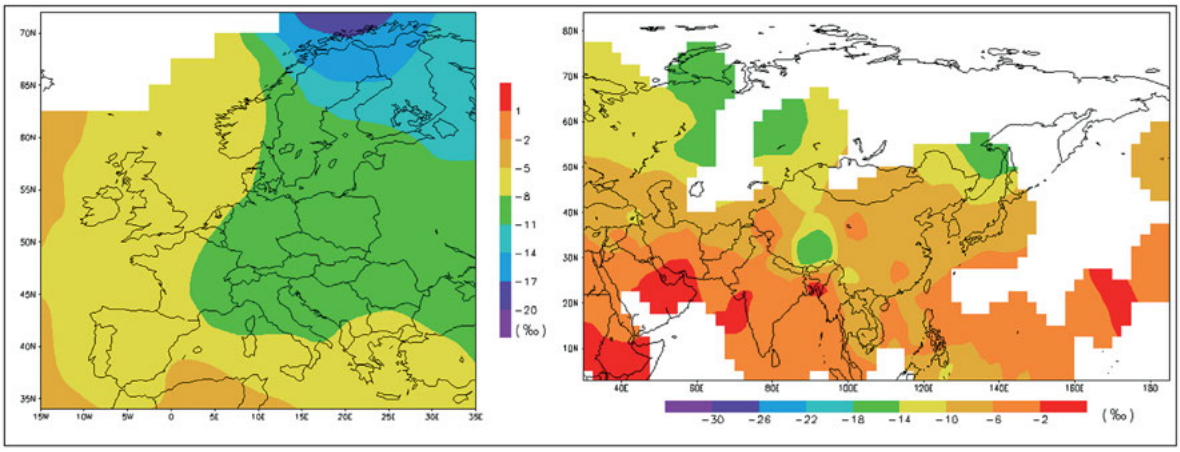


Fig. 4.33 | Long-term annual average $\delta^{18}O$. IAEA/WMO (2006), Global Network of Isotopes in Precipitation. The GNIP database. Accessible at: www-naweb.iaea.org/napc/ih/documents/userupdate/Waterloo/index.html#Regional Maps and Animations (last accessed 10. 08. 11).

4.4.2 Material

In this study, tooth enamel, which reflects the oxygen isotopic signal of early to late infancy depending on the selected tooth, was sampled and analysed. The realities of funding did not allow all the teeth that were analysed for $^{87}Sr/^{86}Sr$ to be tested for $\delta^{18}O$. In the majority of cases, one tooth per individual was selected for oxygen isotope analysis: 68 first, 41 second and 49 third permanent molars and a small number of further teeth (Table 4.7). Where an individual showed striking $^{87}Sr/^{86}Sr$ values, a second tooth was usually sampled. A combination of first and second molars and of first and third molars and seven other pairs of teeth were analysed from 30 human individuals in total. Altogether, 166 human teeth were selected for oxygen isotope analysis. In addition, five horse teeth from Berel' were selected for triple $\delta^{18}O$ analysis.

4.4.3 Method

For oxygen isotope analysis, samples were prepared in the laboratory of the Department of Archaeology and Anthropology at the University of Bristol following the procedure as described in Cahill Wilson et al. (2012); A flexible diamond edged rotary saw was used to cut a longitudinal tooth section. Adhering contaminants and dentine were removed with a tungsten carbide dental burr. The cleaned enamel sections representing between 3 µg and 30 µg were weighed into a clean glass vial. Samples were then sequentially washed and rinsed in Milli-Q water and put in an ultrasound bath three times for 5 minutes. Samples were dried down and ground to a powder in a clean agate mortar. The dried powder was then put into mini-spin tubes and transferred to the Research Laboratory for Archaeology and History of Arts at the University of Oxford where samples were treated as follows (pers. comm. P. Ditchfield, cf. e.g. Pollard et al., 2011b); Samples were rinsed with deionised water and freeze dried overnight (as per Koch et al., 1997). Samples did not get any bleaching or acid etching pre-treatments to avoid unnecessary loss of

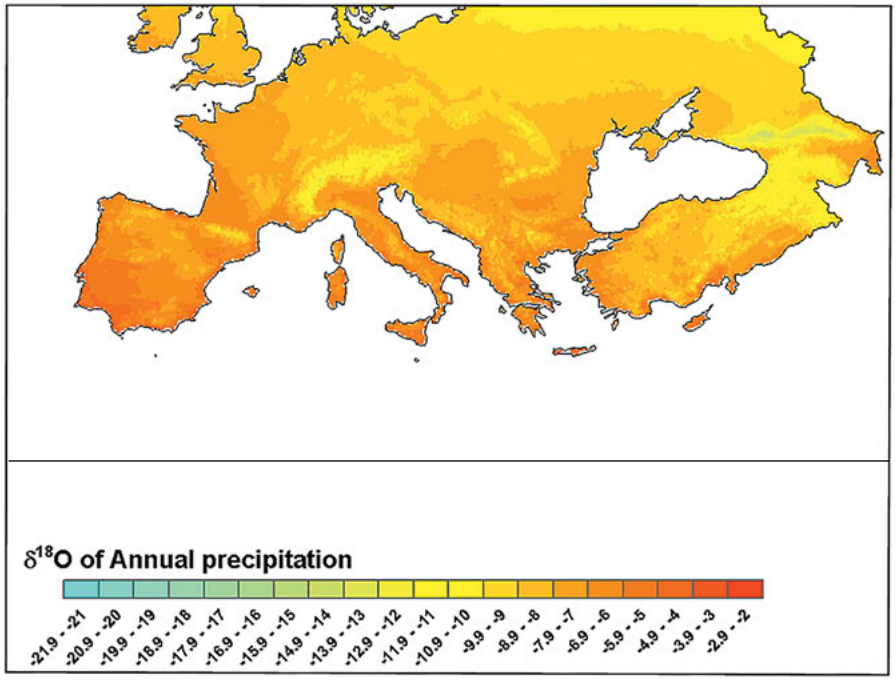


Fig. 4.34 | $\delta^{18}O$ in annual precipitation (http://wateriso.utah.edu/waterisotopes/media/IsoMaps/jpegs/o_Euro/oma_Euro.jpg) (last accessed 10. 08. 11).

material during rinsing. In the Department of Earth Sciences at the University of Oxford, samples were analysed isotopically for $d^{13}C_c$ and $d^{18}O_c$ using a VG Isogas Prism II mass spectrometer with an on-line VG Isocarb common acid bath preparation system where they were reacted with purified phosphoric acid (H_3PO_4) at 90 °C. The evolved CO_2 was pre-concentrated using a 'cold finger' apparatus prior to admission to the dual inlet system on the mass spectrometer. Both oxygen and carbon isotopic ratios were reported relative to the V-PDB international standard. Calibration was against the Oxford in-house NOCZ Carrara Marble standard. Reproducibility was better than 0.2 ‰ (0.02 %). In addition, measurement precision was controlled by the repeated measurement of one study-internal cattle tooth enamel sample from the site of Uivar, Western Romania.

4.4.4 Results $\delta^{18}O_c$ (V-PDB)

The results for $\delta^{18}O_c$ in the dental enamel carbonate are presented in Appendices A and C. In this chapter, results are expressed as Craig-corrected values (Craig, 1957) relative to V-PDB. Mean values are given with 1σ standard deviations. The presentation and discussion of the results in this chapter follows chronological periods and geographical location. Negligible error bars and sample labels are not included in the figures to avoid overloading of information. In order to compare the $\delta^{18}O_c$ values measured in the dental enamel carbonate with other published data and geographic localities, $\delta^{18}O_c$ values were later also converted to V-SMOW and $\delta^{18}O_w$ values.

The replicate values for the NOCZ Carrara Marble standard run with the samples in this study gave an uncorrected mean value of –5.26 ‰ for $d^{18}O_c$ with a standard deviation of 0.15 and an uncorrected

Table 4.7 | Number of human teeth selected for oxygen isotope analysis.

site	canine	premolar 1	premolar 2	deciduous molar 2	molar 1	molar 2	molar 3
Eneolithic and Bronze Age							
Bulgaria					24	4	7
Hungary			2		5	7	3
Ukraine					16	19	17
South Russia	1			4	4	2	4
Volga					11	5	3
Iron Age							
Ukraine					7	4	10
Berel'		1			1		5
n	1	1	2	4	68	41	49

mean value of 0.37 ‰ for $d^{13}C_c$ with a standard deviation of 0.20. This corresponds to a corrected mean value of –1.85 ‰ for $d^{18}O_c$ with a standard deviation of 0.08 and a corrected mean value of 2.10 ‰ for $d^{13}C_c$ with a standard deviation of 0.07 (1σ, n = 61 over 7 analysis runs). The mean batch reproducibility was 0.08 ‰ (1σ, n = 8 per analysis run). The repeated analysis of the cattle tooth enamel averaged in $d^{18}O_c$ –5.18 ± 0.23 ‰ (1σ, n = 7).

4.4.4.1 Eneolithic and Bronze Age

Bulgaria

From the Bulgarian sites, 26 individuals sampled for strontium were also analysed for oxygen (Fig. 4.35). The $\delta^{18}O_c$ (V-PDB) values of the nine humans from Benkovski vary between –5.18 ‰ and –3.29 ‰ with a mean value of –4.16 ± 0.61 ‰ (1σ). The mean value (–4.46 ± 0.74 ‰) and the range from –5.60 to –3.42 ‰ for the seven samples of the five individuals from Boyanovo are comparable to the values from Benkovski. The average oxygen value (–4.24 ± 0.57 ‰) for the five human skeletons from Ovchartsi is also very similar to the two sites mentioned before though the range from –5.18 to –3.52 ‰ is marginally more constrained. The range for the seven individuals from Smyadovo is between –6.71 and –3.84 ‰. The highest value is caused by an outlier, which is the only one similar to the values from the other Bulgarian sites. The mean value of –5.80 ± 0.88 ‰ is much more depleted than the averages of the other sites. Intra-individual measurements differ by 0.15 to 1.72 ‰. The two $\delta^{18}O_c$ values of Boyanovo, grave 14, individual 1 and Smyadovo, grave 6, resemble each other. The largest intra-individual diversity is given by grave 22 in Smyadovo. In total, the $\delta^{18}O_c$ values for the Bulgarian samples show a wide range between –6.71 and –3.29 ‰.

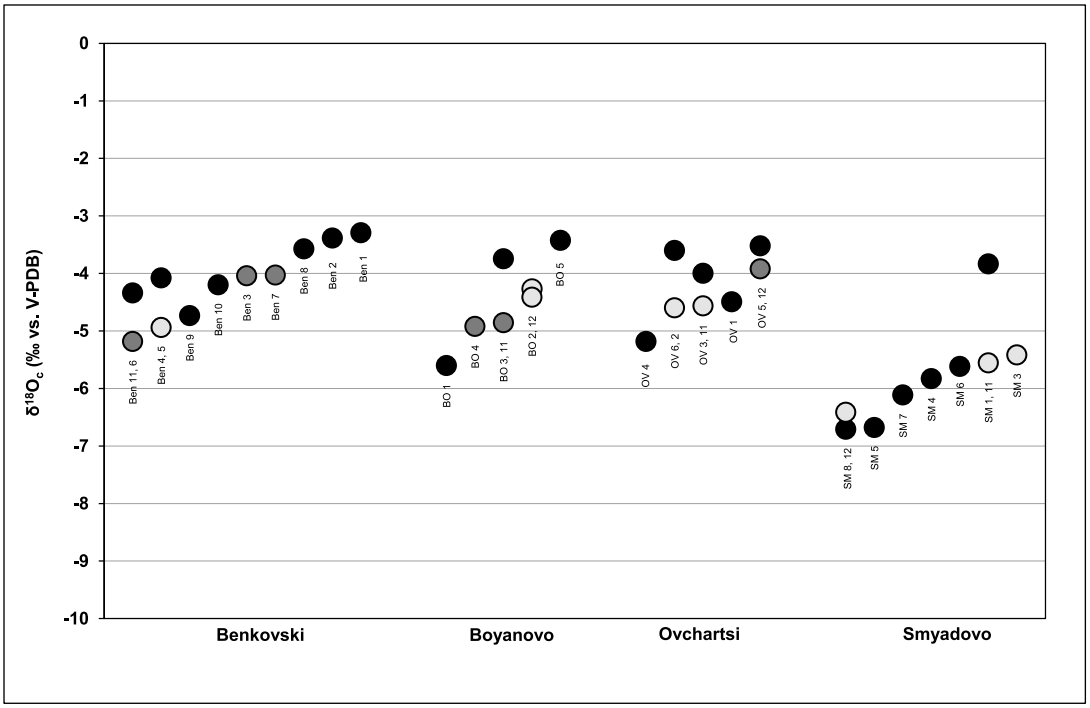


Fig. 4.35 | $\delta^{18}O_c$ (V-PDB) values for the four Bulgarian sites sampled: First molars (black symbols), second molars (light grey), third molars (dark grey). Results from teeth taken from the same individuals are shown in a line.

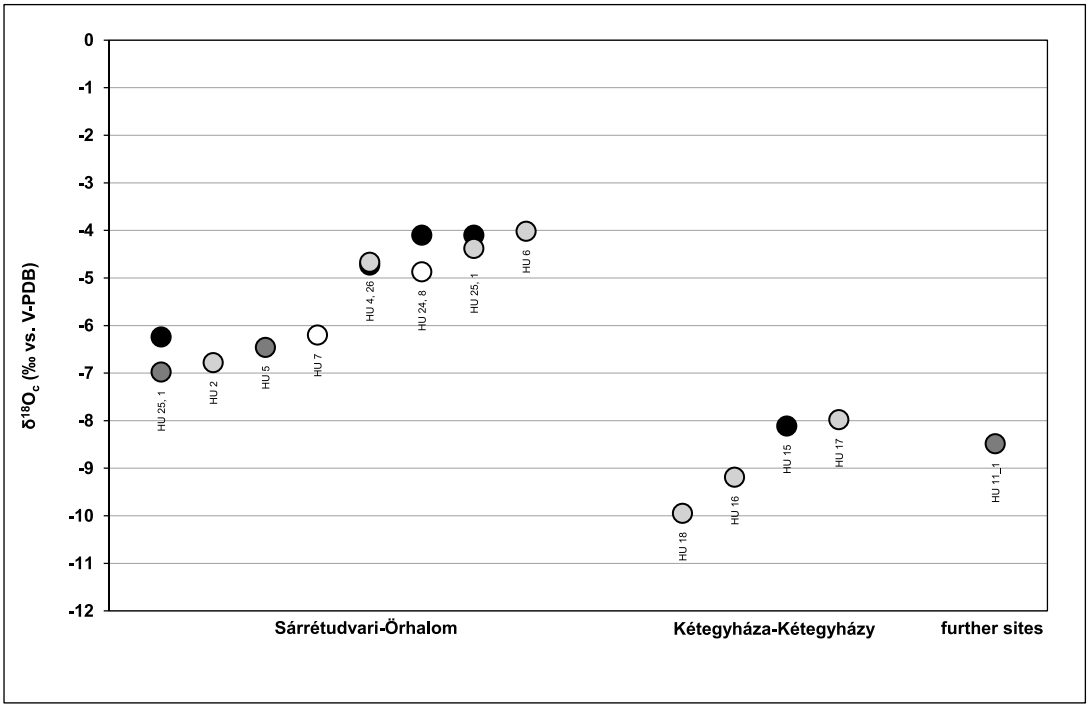


Fig. 4.36 | $\delta^{18}O_c$ (V-PDB) values for the sites Sárrétudvari-Őrhalom, Debrecen-Dunahalom, Kétegyháza in the Eastern Hungarian Plain: First molars (black symbols), second molars (light grey), third molars (dark grey), second premolars (white). Results from teeth taken from the same individuals are shown in a line.

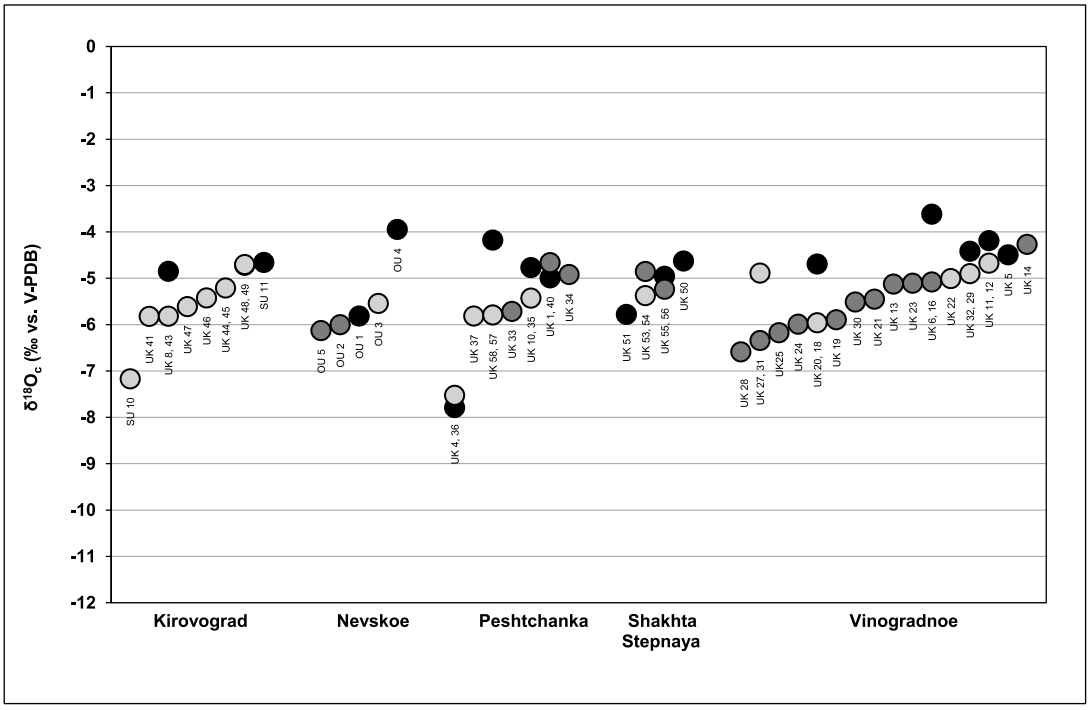


Fig. 4.37 | $\delta^{18}O_c$ (V-PDB) values for the five Ukrainian sites sampled: First molars (black symbols), second molars (light grey), third molars (dark grey). Results from teeth taken from the same individuals are shown in a line.

Hungary

Strontium and oxygen isotope analysis was undertaken at three sites in the East Hungarian Plain. All eight individuals from Sárrétudvari-Őrhalom, the skeleton from Debrecen-Dunahalom and the four sampled individuals from Kétegyháza-Kétegyházi were selected for $\delta^{18}O$ analysis (Fig. 4.36). The $\delta^{18}O_c$ values for the Eastern Hungarian Plain range from –6.98 to –4.02 ‰ with an average value of –5.23 ± 0.96 ‰. This rather low mean can be explained by four of the individuals from Sárretudvari with $\delta^{18}O_c$ values below –6 ‰. If these four burials were ignored, the mean value would be –4.68 ‰. In three of the four cases where duplicate $\delta^{18}O$ analyses were undertaken, the results showed intra-individual variability where the second tooth sampled (PM2, M2, M3) had a more depleted $\delta^{18}O$ value than the first molars. This is possibility due to a weaning effect. Interestingly, the individual in grave 8 from Sárrétudvari-Őrhalom had consistent results in both teeth.

North Pontic region

The average oxygen isotope ratio for all North Pontic sites under investigation is –5.29 ± 0.84 ‰ with a range in $\delta^{18}O_c$ from 7.79 to –3.62 ‰ (Fig. 4.37). The eight individuals from the kurgan Sugokleya near Kirovograd have $\delta^{18}O_c$ values from –7.17 to –4.66 ‰ with a mean value of –5.40 ± 0.77 ‰. The duplicate analysis of UK 55 gave extremely similar results. Eleven humans were sampled singularly and five individuals were analysed in duplicate from the burial mounds 3 and 24 in Vinogradnoe. The results for this site are very inconsistent, with an average value of –5.16 ± 0.78 ‰ and a wide range of values between –6.59 and –3.62 ‰. The intra-individual variation ranges from 0.48 to 1.46. As in all cases, the teeth representing older average ages exhibited more depleted results than the teeth that mineralised in

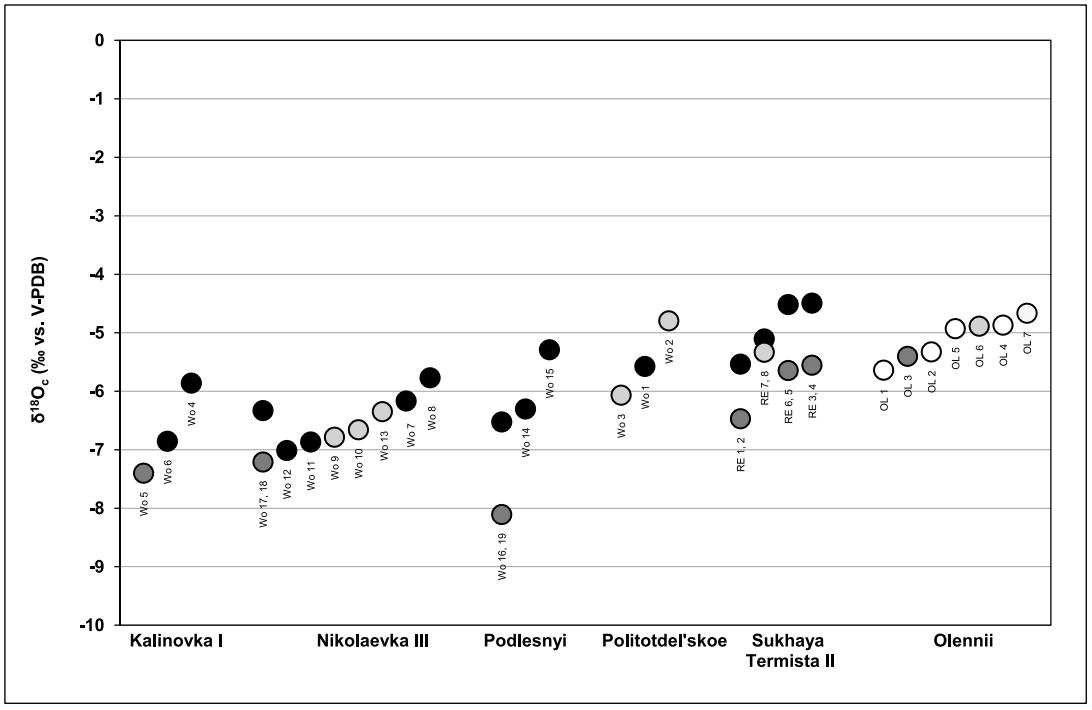


Fig. 4.38 | $\delta^{18}O_c$ (V-PDB) values for the four sites in the Volga region, for Sukhaya Termista II and for Olennii in the Kuban region: First molars (black symbols), second molars (light grey), third molars (dark grey). White circles symbolize second deciduous molars and very light grey circles symbolize canines. Results from teeth taken from the same individuals are shown in a line.

the very early years of life. The results for Peshtchanka display highly variable values ranging from –7.79 to –4.18 ‰. The mean value for this site is –5.60 ± 1.14 ‰. The individual in grave 14 with $\delta^{18}O_c$ values of –7.79 and –7.53 ‰ can clearly be regarded as an outlier. If this grave were ignored, the mean (5.14 ± 0.58 ‰) would be significantly less depleted. Intra-individual variation is from 0.26 to 1.62 ‰. The average value for Shakhta Stepnaya is –5.14 ± 0.41 ‰ with a range of oxygen ratios from –5.78 to –4.63 ‰. This range resembles the ranges of Kirovograd and to a certain degree Peshtchanka, if grave 14 is ignored. Intra-individual variation is very small at this site. In contrast to the four sites in the characteristic steppe environment of south Central Ukraine, the site of Nevskoe is located eastwards, which may explain the slightly more depleted results. One outlier shows an unexpectedly high value of –3.95 ‰. The remaining four values range from –6.13 to –5.54 ‰ with a mean of –5.87 ± 0.26 ‰. Including the outlier the mean (–5.49 ± 0.81 ‰), this is still more depleted than the average values of the other Ukrainian sites.

Volga region

The South Russia and the Volga regions will be addressed separately in a discussion of the results. The four sites that were sampled along the River Volga will be discussed as one Volga unit despite the fact that Politotdel'skoe is situated several hundred km to the south of the remaining three sites in the region of Samara. The expected differences in climate between them are only small, and it is not surprising that the oxygen values from the three sites in the vicinity of Samara give more depleted results (mean

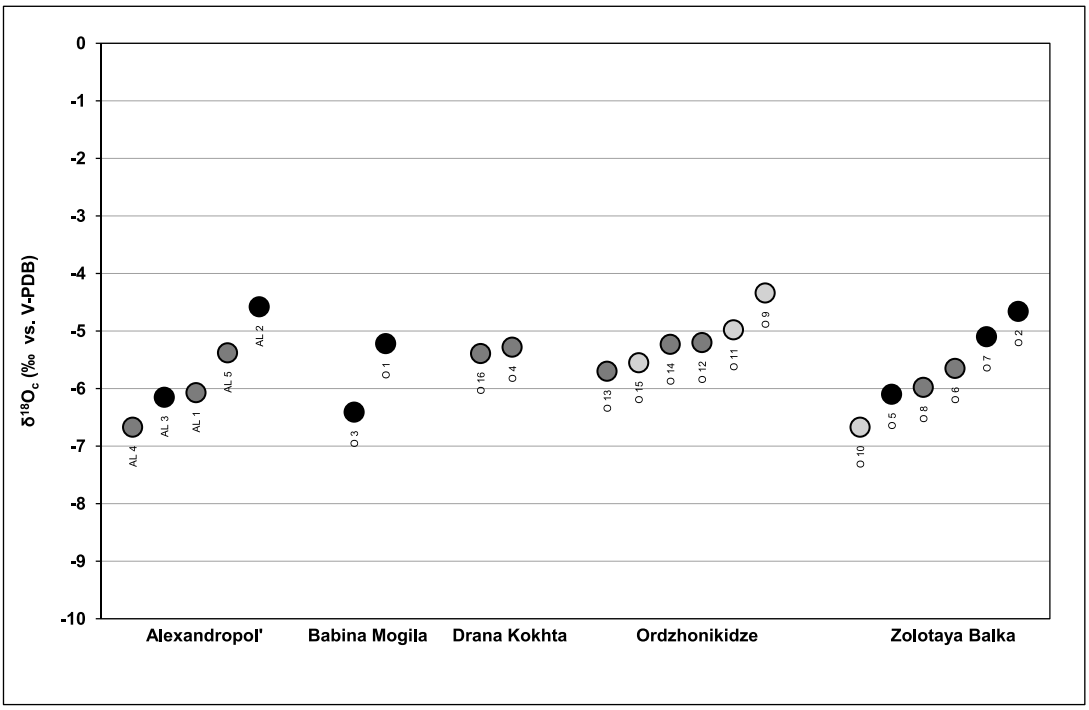


Fig. 4.39 | $\delta^{18}O_c$ (V-PDB) values for the five sites of the Scythian period in the North Pontic region: First molars (black symbols), second molars (light grey), third molars (dark grey). Results from teeth taken from the same individuals are shown in a line.

value –6.59 ± 0.68 ‰) than Politotdel'skoe, the fourth site at the river Volga (average of –5.48 ± 0.64 ‰) (Fig. 4.38). The sites in the Samara region yield $\delta^{18}O$ values ranging between –8.11 ‰ (an outlier value) and –5.29 ‰, but the majority of values range between ~ –7 and ~ –6 ‰. The three samples from Politotdel'skoe feature less depleted values from –6.07 to –4.80 ‰.

Kalinovka I (with a mean value of –6.71 ± 0.78 ‰), Nikolaevka III (with an average of –6.49 ± 0.45 ‰) and Podlesnyi (with a mean of –6.56 ± 0.66 ‰) exhibit very similar results and therefore offer good possibilities for comparison.

South Russia

In South Russia, the sites Sukhaya Termista II and Olennii were selected for analysis (Fig. 4.38). The site of Sukhaya Termista II had an average $\delta^{18}O_c$ value of –5.49 ± 0.55 ‰ and a range from –6.47 to –4.49 ‰. Intra-individual variation is approximately 1 ‰ for three individuals with more depleted values in the second and third molars.

The oxygen isotope ratios for Olennii represent a similar, but more restricted range of –5.64 to –4.66 ‰, despite beeing situated in the southwest. The average $\delta^{18}O_c$ (–5.10 ± 0.35 ‰) for this site is marginally more enriched.

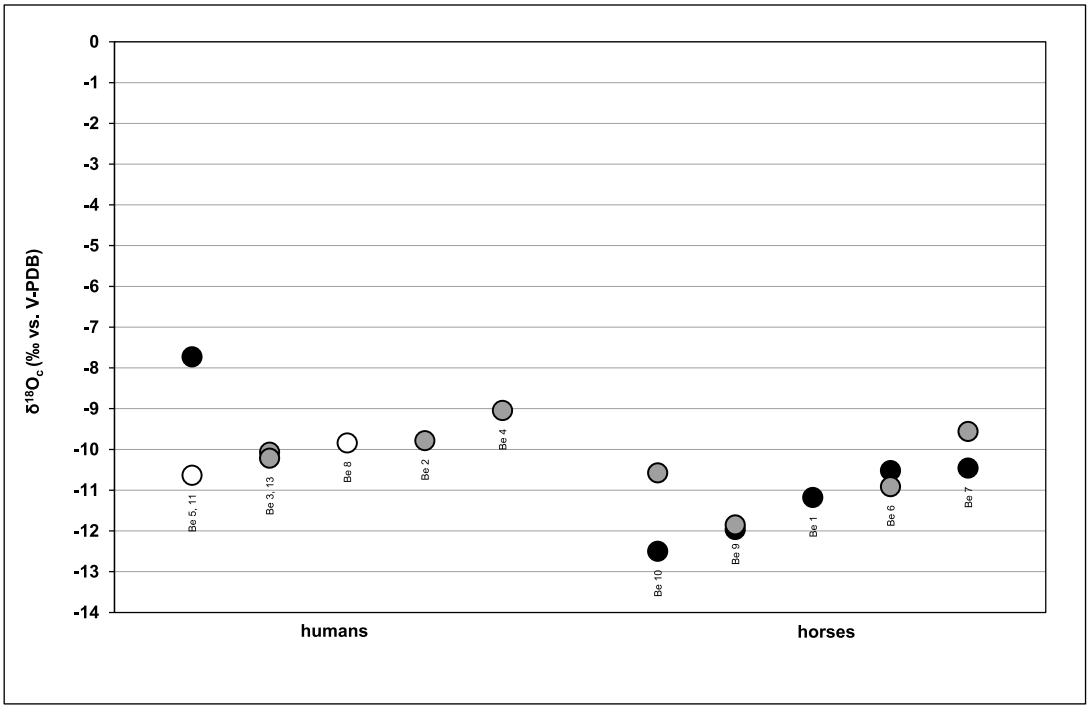


Fig. 4.40 | $\delta^{18}O_c$ (V-PDB) values for Berel' in the Altai Mountains: First molars (black symbols), second molars (light grey), third molars (dark grey). White circles symbolize first premolars and incisors. Results from teeth taken from the same individuals are shown in a line. Horses were sampled at the cusp (black symbols) and cervix (grey symbols).

4.4.4.2 Iron Age

North Pontic region

The 21 individuals from the five nearby sites in theNorthern Pontic region dating to the Scythian period were each sampled once (Fig. 4.39). The Northern Pontic samples as a whole have an average $\delta^{18}O_c$ value of –5.54 ± 0.66 ‰ with the most depleted value being –6.67 ‰ (Alexandropol') and the least depleted value being –4.34 ‰ (Ordzhonikidze). The majority of the values range between –7 ‰ and –6 ‰. Analogical $\delta^{18}O_c$ averages are shown for the sites of Alexandropol' (–5.77 ± 0.81 ‰), Babina Mogila (–5.82 ± 0.84 ‰) and Zolotaya Balka (–5.70 ± 0.72 ‰). To a minor degree, the mean values from Drana Kokhta (–5.33 ± 0.08 ‰) and Ordzhonikidze (–5.17 ± 0.48 ‰) are less depleted.

Berel' (Kazakhstan)

The six human individuals from Berel' average at –9.74 ± 1.00 ‰, with the most depleted value being –10.63 ‰ (Be 5), and the least depleted being –7.73 ‰ (Be 11) (Fig. 4.40). Astonishingly, these two extremes derive from the same individual. The other individual selected for duplicate analyses showed almost no variation between the two teeth sampled.

The five horse teeth were sampled vertically, at the top and bottom of the section (Be 1 vertically only due to failed measurements). The values range from –12.50 to –9.56 ‰ and average at –10.68 ± 0.98 ‰. Be 10 is the only sample that shows a large variation between the top and bottom of the tooth section.

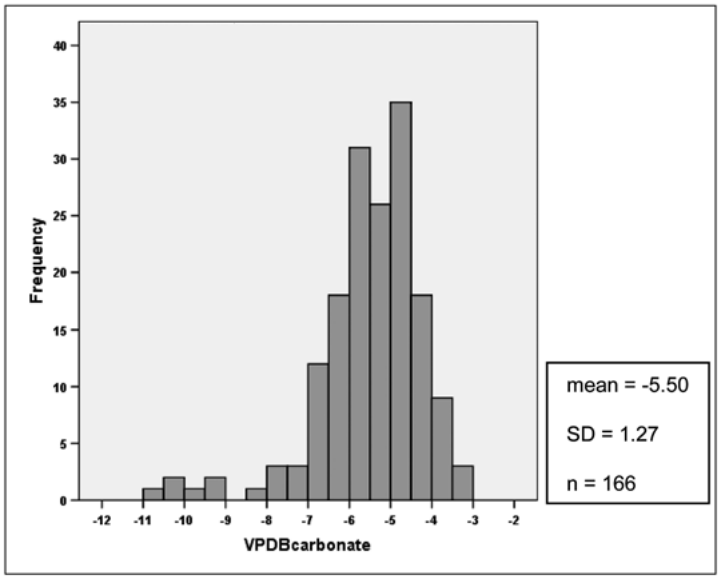


Fig. 4.41 | Distribution of $\delta^{18}O_c$ (V-PDB) values of the Eneolithic, Bronze Age and Iron Age samples.

4.4.4.3 Intra-site and inter-site comparison

A histogram (Fig. 4.41) shows the distribution of the $\delta^{18}O$ in the carbonate fraction of human tooth enamel of the Eneolithic, the Bronze Age and the Iron Age samples. It is clear from the histogram that the main cluster of values is from –4.5 to –6 ‰.

A small number of values from Berel' cluster below –8.5 ‰, which makes the mean of –5.5 ‰ slightly more negative. Table 4.8 shows $\delta^{18}O_c$ (V-PDB) minima, maxima, ranges and mean values with standard deviations. Results are summarized as distinct regions. The $\delta^{18}O_c$ ranges are between 0.98 in Olennii and 4.17 in Central Ukraine. The least depleted mean values can be found in Bulgaria (4.66 ± 0.95 ‰). Most mean values lie between 5 and 6 ‰, with eastern areas, the Volga region (6.42 ± 0.76 ‰) and Berel' (9.74 ± 1.0 ‰), showing more depleted values. Due to differences in nutrition and physiology, there is variability within the $\delta^{18}O$ values of the same population. The degree of the variability in human populations is not well known but empirical data suggests a variability of approximately ± 1 ‰ (Longinelli, 1984) to 2 ‰ (White et al., 2004b). Even if the same sources of drinking water are exploited, a certain degree of intra-population variability is to be expected. In the case of the present study this is crucial, as the human individuals in one burial mound did not necessarily belong to the same community, introducing the possibility that they exploited different water sources. According to M. Vohberger, who applied the same conversion equations (Iacumin et al., 1996; Longinelli, 1984) on her data set, the propagation of uncertainty totals at 1.59 when converting results from $\delta^{18}O_c$ (V-PDB) into $\delta^{18}O_w$ (V-SMOW) (cf. Vohberger, 2011, 118–119 for detailed discussion). In consequence, an intra-population variability would normally be around 1 ‰ is increased to 1.59 ‰ (Vohberger, 2011, 119).

Table 4.8 | Ranges, minimum, maximum and mean values including standard deviations of $\delta^{18}O$ in the carbonate of tooth enamel at sites and regions.

site/region	range	minimum $\delta^{18}O_c$ (‰ vs. V-PDB)	maximum $\delta^{18}O_c$ (‰ vs. V-PDB)	mean $\delta^{18}O_c$ (‰ vs. V-PDB)	SD
Eneolithic and Bronze Age					
Bulgaria	3.42	–6.71	–3.29	–4.66	0.95
Hungary	2.96	–6.98	–4.02	–5.22	0.96
Central Ukraine	4.17	–7.79	–3.62	–5.28	0.80
East Ukraine	2.18	–6.13	–3.95	–5.49	0.79
Sukhaya Termista II	1.95	–6.47	–4.52	–5.49	0.52
Olennii	0.98	–5.64	–4.66	–5.10	0.33
Volga	3.31	–8.11	–4.8	–6.42	0.76
Iron Age					
North Pontic	2.33	–6.67	–4.34	–5.54	0.64
Berel'	2.90	–10.63	–7.73	–9.53	0.90

Box plots of the single sites dating to the Eneolithic and Bronze Age (Fig. 4.42) show the gradient from least depleted $\delta^{18}O_c$ means and ranges in the Carpathian-Balkan and most depleted ones in the Volga region. There is a clear gradient from southwest to northeast. The three sites in Bulgaria show the most enriched values. Smyadovo (SM), however, is totally different and yields even more depleted values than the North Pontic sites and is comparable to the East Ukrainian site Nevskoe (OU). Some of the results from Sárrétudvari (SA) are similar to the Smyadovo ones, while the rest are less depleted in $\delta^{18}O_c$. The means of the two Hungarian sites therefore lie between the Bulgarian and the Ukrainian average values. Though the ranges of the Central Ukrainian sites differ a lot, the means of all four sites are very similar. Nevskoe in East Ukraine exhibits more depleted $\delta^{18}O_c$ values than the two sites in South Russia. Despite the comparatively large geographical distance between Sukhaya Termista II (RE) and Politotdel'skoe (Polit), their mean $\delta^{18}O_c$ values correspond. The three sites in the Samara region are similar to one another but considerably offset compared to all other sites.

Approximately half of the sites show $\delta^{18}O_c$ distributions with trailing 'tails' to either the depleted or enriched side. There are only few statistical outliers: one from Smyadovo, one individual (both results) from Peshtchanka (PE), two values from Sukhaya Termista II and one from Nevskoe. The $\delta^{18}O_c$ values are normally distributed ($Z = 1.04$, $p = 0.23$; Kolmogorov-Smirnov test) and a Levene test proves the homogeneity of the variances ($F = 1.39$, $p = 0.15$). The performance of a one-way ANOVA showed that differences between the $\delta^{18}O_c$ values of the sites are statistically significant ($F = 14.14$, $p < 0.001$).

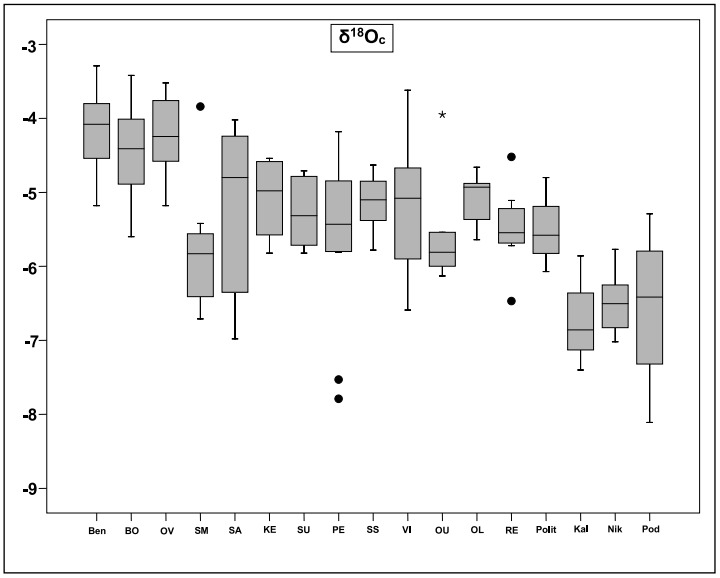


Fig. 4.42 | Box plots of the Eneolithic and Bronze Age sites sampled for $\delta^{18}O_c$ (V-PDB).

4.4.4.4 Inter-regional comparison

The trend from least depleted $\delta^{18}O_c$ in the southwest of the study area to most depleted values in the northeast is evident when data is shown in box plots according to sub-regions (Fig. 4.43). Even though Nevskoe shows more depleted values than the Central Ukrainian sites, the mean, the range and the statistical outliers are not affected by the inclusion of the Nevskoe results. Interestingly, the mean of the $\delta^{18}O_c$ values from the south Russian sites (Sukhaya Termista II and Olennii) corresponds with that of the North Pontic. The null hypothesis of the homogeneity of variances can be accepted on a 5% level of significance ($F = 2.48$, $p = 0.05$). The performance of a one-way ANOVA showed that differences between the regional $\delta^{18}O$ values are statistically highly significant ($F = 12.25$, $p < 0.001$). A Tukey's HSD post hoc test showed that significant differences exist between the Volga and all other regions ($p < 0.002$) and between Bulgaria and the North Pontic region ($p = 0.007$). Both study areas from the Scythian period, the site of Berel' and the cluster of sites in the North Pontic region feature a distinct spread of $\delta^{18}O_c$ values (Fig. 4.44).

4.4.4.5 Gender and age related differences

4.4.4.5.1 Eneolithic and Bronze Age

The box plots in Figure 4.45 show the mean (median) $\delta^{18}O_c$ (V-PDB) values including standard deviations for males, females and skeletons of undetermined sex.

The box plot for the Carpathian-Balkan region (a) includes the Bulgarian sites (Ben, Bo, Ov, Sm) and the Hungarian sites (HU). Male individuals from Smyadovo and the Hungarian sites show more

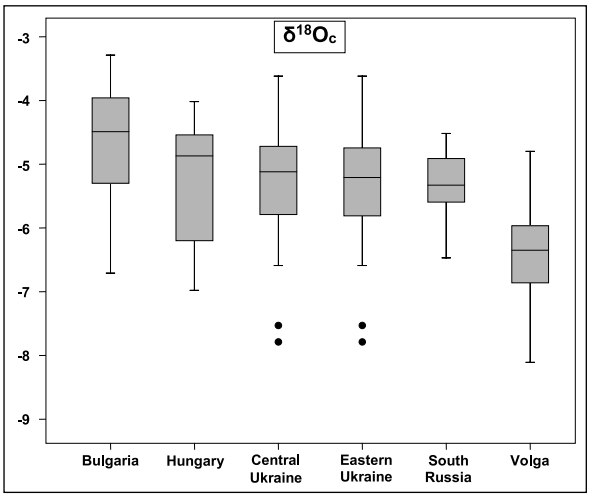


Fig. 4.43 | Box plots of regions summarizing the Eneolithic and Bronze Age sites sampled for $\delta^{18}O_c$ (V-PDB).

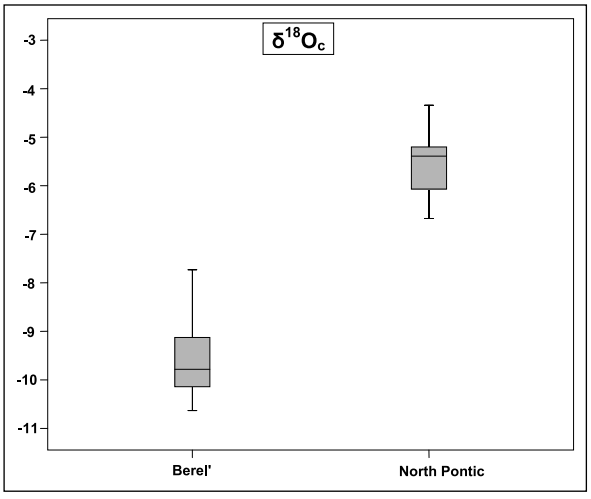


Fig. 4.44 | Box plots of the Iron Age sites sampled for $\delta^{18}O_c$ (V-PDB).

depleted $\delta^{18}O_c$ values than females and undetermined individuals at the same sites and also have more depleted means than are typical for the Carpathian-Balkan region. This pattern is not observed in Benkovski and Ovchartsi, where the $\delta^{18}O_c$ values of males were equal to or less depleted than the undetermined skeletons. According to a Kruskal-Wallis test, the differences were not significant ($x^2 = 1.41$, $p = 0.5$).

Males also generally have more depleted $\delta^{18}O_c$ values in the North Pontic region (b). In Kirovograd, on the other hand, the reverse is the case. Based on normal distribution and the homogeneity of variances ($F = 2.33$, $p = 0.11$; Levene test) a one-way ANOVA was performed, which showed that differences were not significant ($F = 0.62$, $p = 0.54$).

The Russian sites show no consistent pattern (c). Single individuals other than males were only sampled at Kalinovka, Nikolaevka and Podlesnyi, which makes comparing the data difficult. The same is true for Olennii and Politotdel'skoe. Gender-based differences can only be observed in Kalinovka, where the only female is more depleted in $\delta^{18}O_c$ than two males. In Politotdel'skoe two undetermined skeletons show more depleted $\delta^{18}O_c$ values than one male. In Sukhaya Termista II (RE) males and undetermined skeletons show similar and less depleted $\delta^{18}O_c$ values than the woman. Again, for the Russian sites there were no statistically relevant differences ($F = 2.67$, $p = 0.09$; one-way ANOVA) and due to small sample sizes observations must remain tentative.

No striking age-related differences were seen for Benkovski and Ovchartsi (Fig. 4.46). The Hungarian sites, however, show variations between lower $\delta^{18}O_c$ values of adult and mature individuals when compared to infants and juveniles. Statistically, differences were not relevant ($x^2 = 4.78$, $p = 0.31$; Kruskal-Wallis test; based on the heterogeneity of variances: $F = 3.36$, $p = 0.02$). The sample set in the North Pontic region consists mainly of adult individuals, and no significant differences based on age groups can be recognized ($F = 2.71$, $p = 0.06$; one-way ANOVA). The interpretation of the data from the Russian sites is compromised as the sample sizes were so small. At sites where more than one individual per age group was analysed, no significant differences were found. This is also supported by the results obtained from a one-way ANOVA ($F = 1.15$, $p = 0.35$).

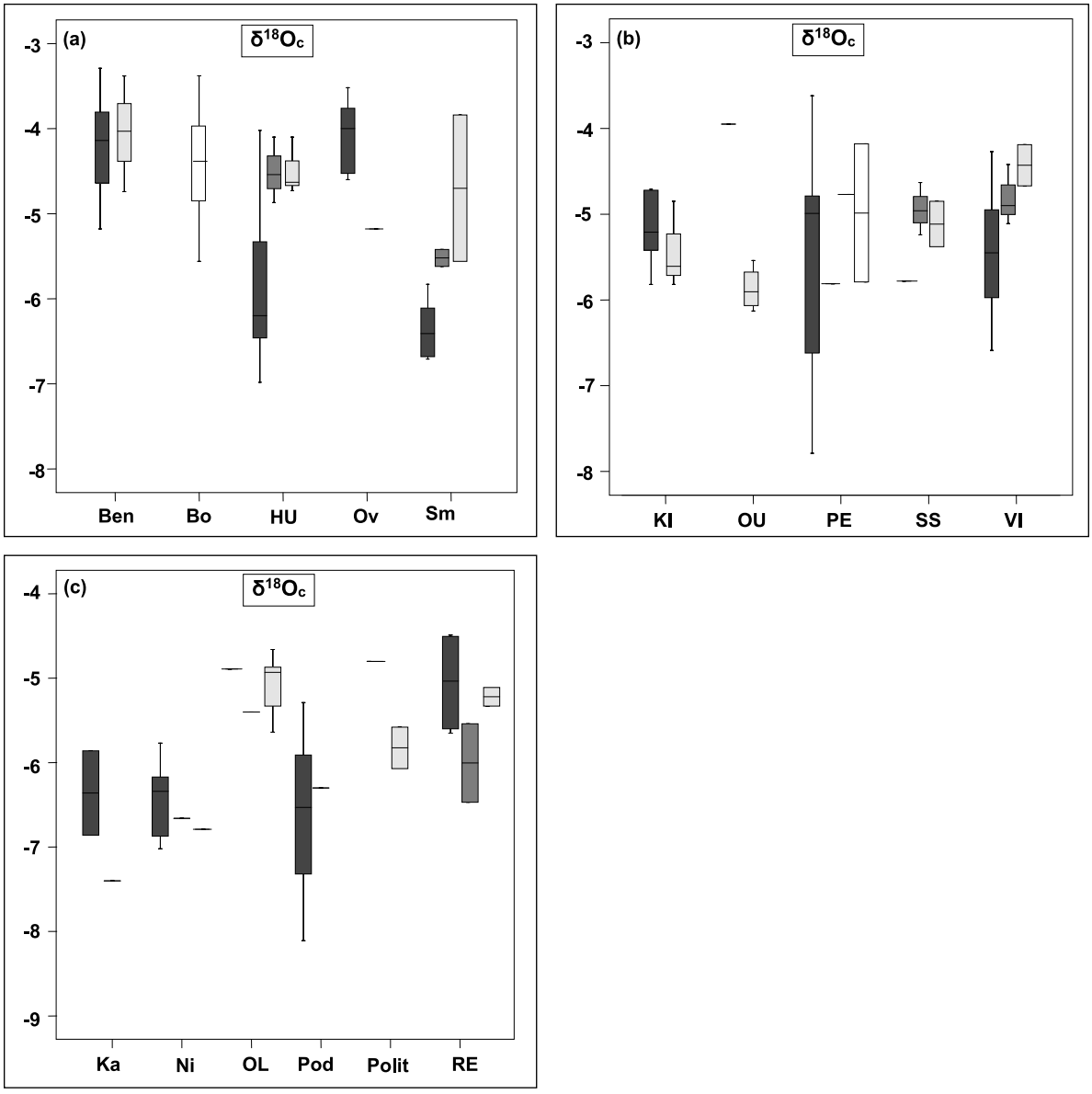


Fig. 4.45 | Box plots of the $\delta^{18}O_c$ (V-PDB) values of males (black symbols) and females (dark grey), skeletons with undetermined sex (light grey) and anthropologically non-determined skeletons (white) of the Carpathian-Balkan (a), North Pontic (b) and Russian (c) sites.

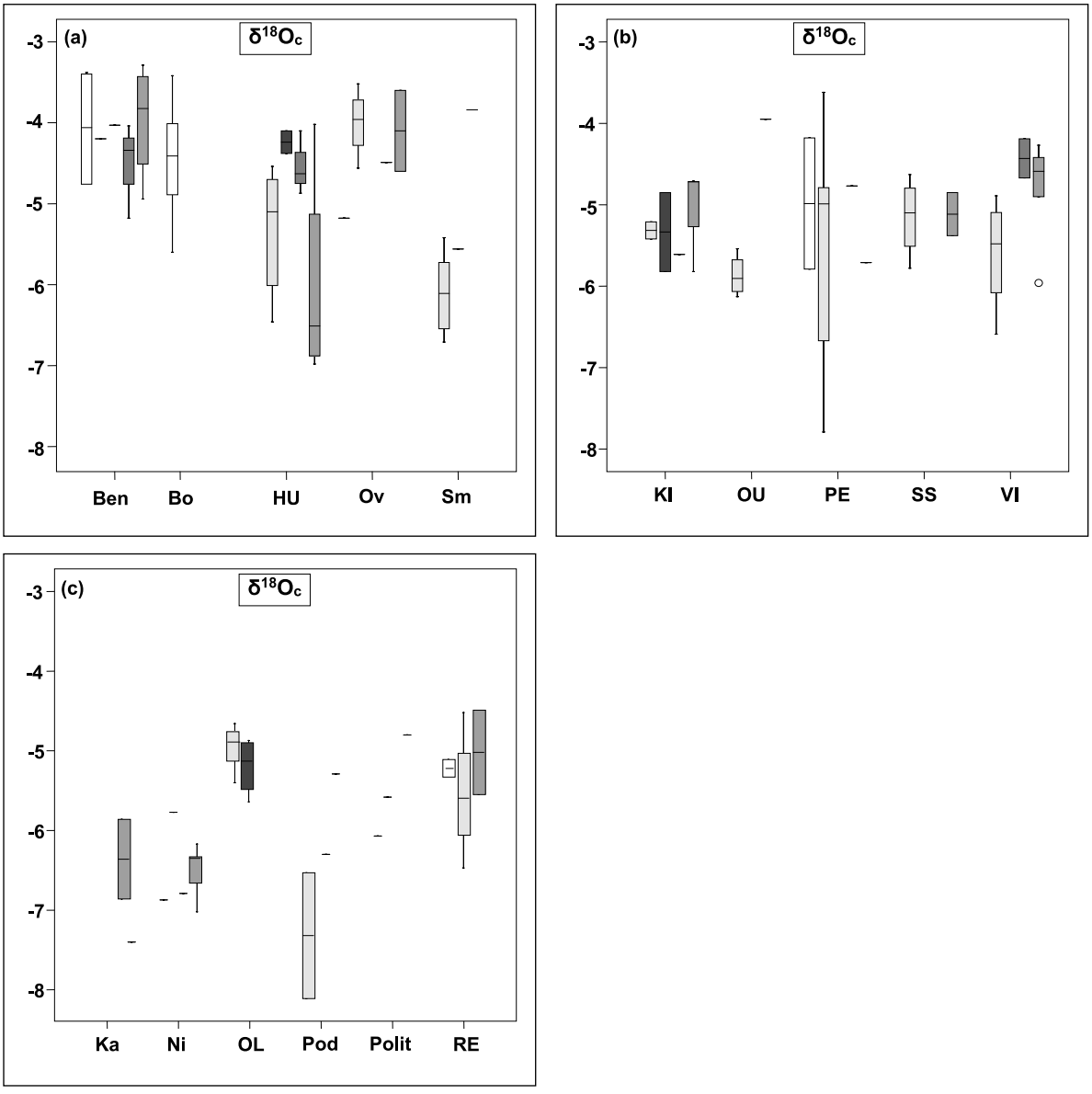


Fig. 4.46 | Box plots of the $\delta^{18}O_c$ (V-PDB) values of infants (light black symbols), juveniles (dark grey), adult (light grey), mature (medium grey) and senile (black) individuals of the Carpathian-Balkan (a), North Pontic (b) and Russian sites (c). Anthropologically undetermined skeletons are coloured white.

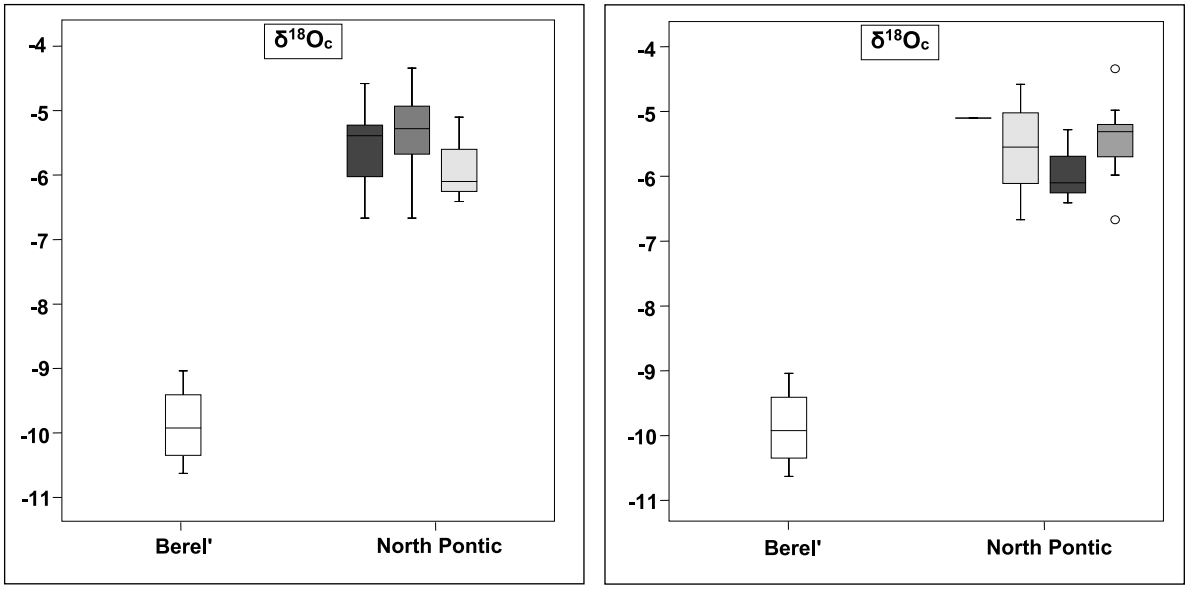


Fig. 4.47 | Box plots of the $\delta^{18}O_c$ (V-PDB) values of males (black symbols) and females (dark grey), skeletons with undetermined sex (light grey) and anthropologically non-determined skeletons (white) of the sites of Scythian date (to the left) and box plot of the $\delta^{18}O_c$ (V-PDB) values of infants (light black symbols), juveniles (dark grey), adult (light grey), mature (medium grey), senile (black) anthropologically non-determined skeletons (white) of sites of Scythian date (to the right).

4.4.4.5.2 Iron Age

The box plot (Fig. 4.47) shows the means of the male and female individuals as well as skeletons of unknown gender from the North Pontic region and the non-gender-determined skeletons from Berel'. In the North Pontic both, males and females have similar mean values and ranges in $\delta^{18}O_c$, whereas the three skeletons of unknown gender are on average approximately 0.5 ‰ more depleted. No significant difference can be seen according to age groups.

4.4.4.5.3 Comparison on a regional scale

On a regional scale there are no major differences in the mean $\delta^{18}O_c$ of males, females and individuals of unknown gender (Fig. 4.48). With the exception of the Scythian samples in the North Pontic region, adult individuals tend to show lower $\delta^{18}O_c$ values than infants and juveniles, but the differences are only small.

Box plot of the $\delta^{18}O_c$ (V-PDB) values of males (black symbols) and females (dark grey), skeletons with undetermined sex (light grey) and anthropologically non-determined skeletons (white) from all regions (to the left) and box plot of the $\delta^{18}O_c$ (V-PDB) values of infants (light black symbols), juveniles (dark grey), adult (light grey), mature (medium grey), senile (black) anthropologically non-determined skeletons (white) from all regions (to the right).

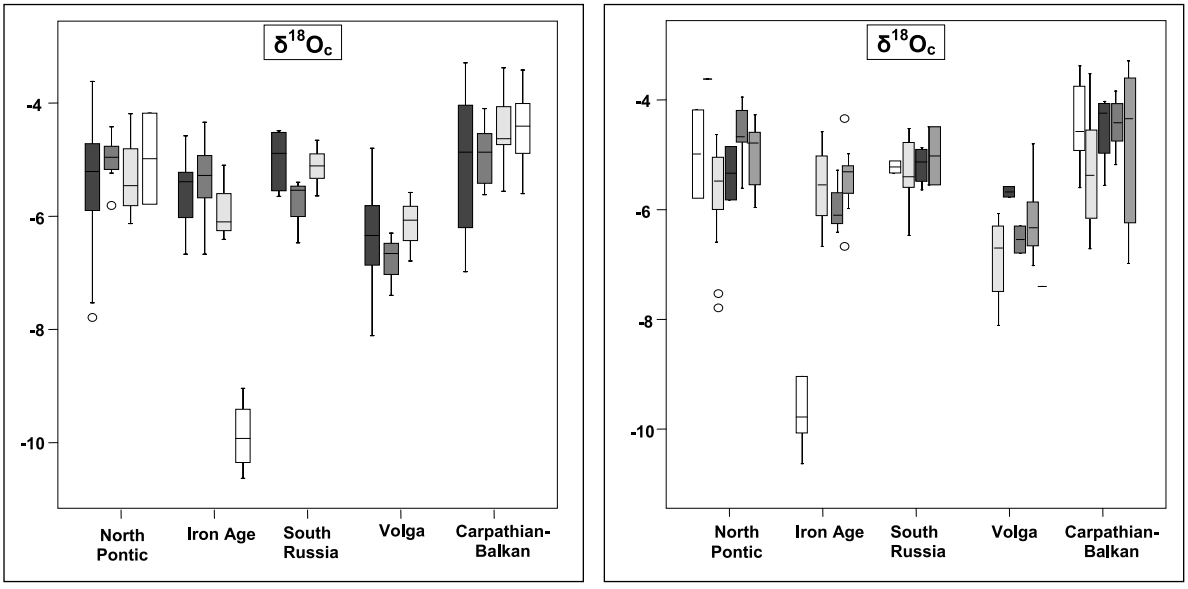


Fig. 4.48 | Box plot of the $\delta^{18}O_c$ (V-PDB) values of males (black symbols) and females (dark grey), skeletons with undetermined sex (light grey) and anthropologically non-determined skeletons (white) from all regions (to the left) and box plot of the $\delta^{18}O_c$ (V-PDB) of infants (light black), juveniles (dark grey), adult (light grey), mature (medium grey), senile (black) anthropologically non-determined skeletons (white) from all regions (to the right).

4.4.4.6 Chronological differences

Chronological differences in $\delta^{18}O_c$ are only recognisable at sites where several individuals from the varying time periods were analysed (Fig. 4.49). Only a small number of sites offered this possibility for comparison. Variations can be seen in the Hungarian sample sites, where earlier graves show higher $\delta^{18}O_c$ values than burials dating to the later period. Furthermore, the Eneolithic individuals in Smyadovo represent the most $\delta^{18}O_c$ depleted samples in the Carpathian-Balkan region. Chronological differences in the Carpathian-Balkan region are confirmed by a one-way ANOVA, which showed that there were significant differences between the Eneolithic and the Bronze Age samples ($F = 4.19$, $p = 0.21$), but these differences are probably due to varying locations. In the North Pontic region, however, $\delta^{18}O_c$ values of the Eneolithic individuals are generally more depleted in comparison to those of the Bronze Age skeletons. This is the case in Peshtchanka and Vinogradnoe. No general trend can be observed between individuals belonging to Yamnaya and those of the subsequent Catacomb cultural groups. Differences cannot be confirmed by statistical analysis ($x^2 = 1.68$, $p = 0.64$; Kruskal-Wallis test). The Russian sites, which are affiliated to only two cultural groups, were excluded from statistical analysis.

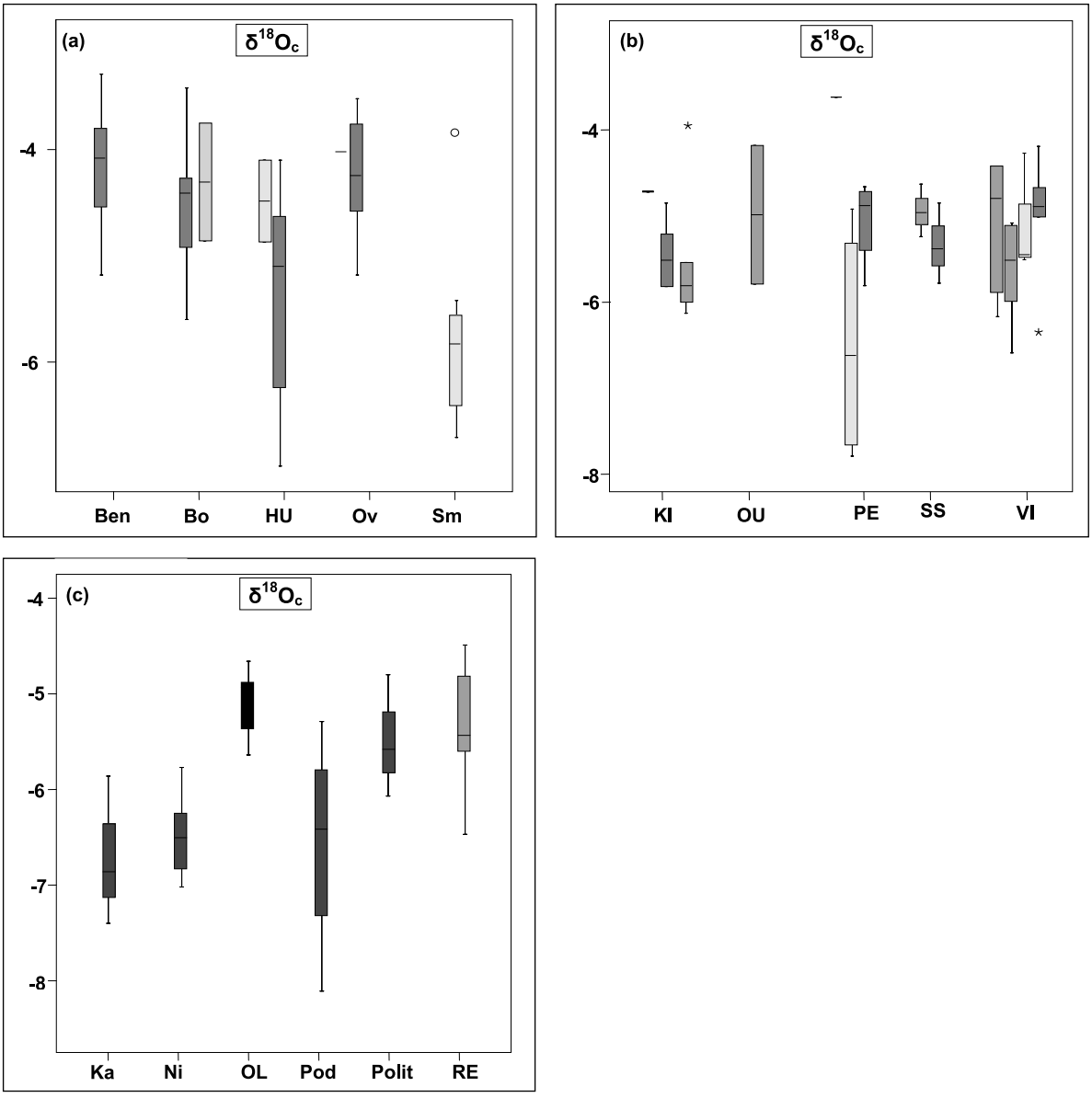


Fig. 4.49 | Box plots of the $\delta^{18}O_c$ (V-PDB) values of skeletons dating to the Copper Age/Eneolithic (light grey symbols), Early Bronze Age/Yamnaya (dark grey), Middle Bronze Age (light medium grey), Catacomb culture (medium grey), Poltavka culture (light black) and Novotitarovskaya culture (black) in the Carpathian-Balkan (a), the North Pontic region (b) and in Russia (c).

4.4.5 Biological measurements of $\delta^{18}O$

4.4.5.1 Estimation of the 'local' $\delta^{18}O$ range

Local $\delta^{18}O$ ranges form the basis for distinguishing 'locals' and 'non-locals' or individuals with a higher degree of mobility. In contrast to $^{87}Sr/^{86}Sr$ analysis, the direct comparison of the data to baseline samples, such as the measurement of $\delta^{18}O$ in faunal remains or environmental samples is difficult due to differences in the diet of mammals and fractionation effects in the body (Killgrove, 2010, 245).

Published human and faunal data with equivalent spatial and temporal contexts published modern water values and modern $\delta^{18}O$ in precipitation offer possibilities for comparison. M. Vohberger suggests taking the mean $\delta^{18}O_c$ (V-PDB) of the human individuals that are regarded as locals according to their $^{87}Sr/^{86}Sr$ ratios and adding a deviation of ± 1 ‰ for the intra-population variation (Vohberger, 2011, 177–178). For data verification she compares the established range with published $\delta^{18}O_c$ (V-PDB) values of the same region. A marginally modified version of Vohberger's approach will be adopted in this study. Due to small sample sizes, all the individuals from a site are used to establish the 'local' range of $\delta^{18}O$ and only extreme outliers are excluded. Furthermore, comparison is made to $\delta^{18}O_w$ values and local ranges are given with standard deviations of ± 1 ‰ and ± 1.59 ‰ (Vohberger, 2011, 118–119; cf. Chapter 4.4.4.3).

4.4.5.2 Published data of $\delta^{18}O$ in humans and animals

$\delta^{18}O$ ratios of humans and animals living locally, preferably prehistoric, provide the best basis for comparison. At present only a few isotopic studies have been conducted in the study region. A large study was carried out and published by Iacumin et al. (2004a, b) on oxygen isotopes from mammal bones at Holocene sites in European Russia. Some of the sites sampled, Abganerovo, Ipatovo, Mandzhikiny, Mu-Sharet and Ostrov, are situated in the area between the Don and Volga rivers in the south Russian steppe belt. Human individuals dated before 3000 BP were selected as references and are presented in Table 4.9. The $\delta^{18}O_w$ values of the human individuals per site average between –12.09 ‰ at Mu-Sharet and –11.4 ‰ at Abganerovo. There is a general trend from slightly more depleted means (–12.00 ‰ for the 3rd millennium BC) to less depleted $\delta^{18}O_w$ means (–11.20 ‰ for the 2nd millennium BC and –11.14 ‰ for approximately 1000 BC) over time.

The region most suited for comparison with the study area is the site of Sukhaya Termista II. However, this area gave a relatively enriched mean $\delta^{18}O_w$ of –9.34 ‰ that was unexpected. These values remain relatively enriched when the $\delta^{18}O_p$ average values of the site are considered. The people buried at Sukhaya Termista II must have used a drinking water source with significantly less depleted $\delta^{18}O$. This is also true for the site of Olennii. If the people there had a cuisine that included significant amounts of dairy products, this may have enriched the isotopic signal. The values presented in the study of Iacumin are much more similar to the $\delta^{18}O$ values obtained for the Volga region.

Iacumin et al. (2004b) also published comparable faunal oxygen isotope values (Table 4.10), giving a general idea of $\delta^{18}O$ values in the study region. Various factors combine to make the direct comparison of $\delta^{18}O$ values in humans and animals challenging (Killgrove, 2010, 250). One such factor is the possibility that humans and animals had different water sources. Furthermore, plants in arid environments tend to have enriched levels of ^{18}O, which leads to enriched $\delta^{18}O$ in the body water of the animals that feed on them (Luz/Kolodny, 1985). In addition to this, humans are more likely to eat cooked food (Kill-

Table 4.9 | Comparative results for $\delta^{18}O_p$ in human tooth enamel. $\delta^{18}O_w$ values after Iacumin using the equation from Longinelli, 1984 (after Iacumin et al., 2004b, 42–43 table 2).

site	~ age BP	$\delta^{18}O_p$ (‰)	$\delta^{18}O_w$ (‰)
Abganerovo	5000		–13.1
	3950–3730		–12.6
	3750–3650		–11.4
	3750–3650		–10.9
	3750–3650		–10.9
	3650		–10.7
	3650		–10.9
	3450–3250		–10.7
Ipatovo	5000–4000		–11.4
	4000		–12.8
Mandjikiny	5000–4500	24.0	–11.8
	4700–4500	24.2	–11.5
	4700–4500	23.3	–12.4
	4700–4500	23.4	–12.5
	4700–4500	23.0	–12.3
	4700–4500	23.8	–11.5
	4700–4500	24.0	–11.4
Mu-Sharet	5000–4500	23.8	–12.0
	5000–4500	23.4	–12.3
	5000–4500	24.5	–11.6
	5000–4500	23.1	–12.4
	4700–4500	23.2	–12.4
	4700–4500	23.0	–12.4
	4500–4000	22.8	–13.5
	4500–4000	23.6	–11.6
	3700–3300	24.2	–11.0
	3500–3100	24.0	–11.7
Ostrov	4500	24.2	–11.9
	4500–4000	24.7	–10.9
	4500–4000	24.4	–11.0
	3000	24.1	–10.9
	3000	23.8	–11.2
	3000	23.9	–12.1
	3000	24.3	–11.1
	3000	24.5	–10.4

Table 4.10 | Comparative results for $\delta^{18}O$ in faunal tooth enamel. $\delta^{18}O_w$ values after Iacumin using the equations from D'Angela/Longinelli, 1990 (after Iacumin et al., 2004b, 42–43 table 2).

site	specimen	~ age BP	$\delta^{18}O_w$ (‰) (vs. V-SMOW)
Abganerovo	sheep	3750–3650	–5.7
	sheep	3750–3650	–7.6
	sheep	3650	–6.1
	sheep	3650	–6.7
	sheep	3450–3250	–5.8
	cattle	3950–3750	–11.6
	cattle	3750–3650	–9.2
Black Sea coast (Kuban)	cattle	6000	–9.0
	cattle	6000	–8.9
	deer	6000	–8.3

grove, 2010, 245–247), which will lead to relatively enriched $\delta^{18}O$ values. Although physiological fractionation processes are species-dependent, they can be calibrated by the use of species-specific calibration equations. When compared to humans from the same site, most animals had significantly less depleted $\delta^{18}O$ values. The data shows that the earlier cattle and deer samples from the Kuban region are more depleted in $\delta^{18}O$ than the temporally later sheep samples from Abganerovo. The cattle samples from the latter site, however, have the same range of values as the animals from the first site. These variations might be explained by the use of species-specific fractionation equations. The faunal $\delta^{18}O$ values match the results presented in this study better than those of the human values. This is especially true for the Black Sea coast.

The North Pontic results can be compared to the carbon and oxygen isotopic results for three Scythian burials in the Alexandropol' kurgan published by Wentz and de Grummond (Wentz/de Grummond, 2009, 114). Burial 1, the skeleton of a young man, yielded $\delta^{18}O$ –4.5 ‰ (V-PDB; –7.91 ‰ $\delta^{18}O_w$ using Longinelli, 1984) in the tooth enamel carbonate, burial 2, a mature man, yielded a $\delta^{18}O_c$ value of –4.6 ‰ (V-PDB; –8.07 ‰ $\delta^{18}O_w$), and burial three a value of –5.7 ‰ (V-PDB; –9.77 ‰ $\delta^{18}O_w$). Despite the fact that the three skeletons show a range of almost 2 ‰ and there is no information on whether they are suspected of having lived locally, the values are within the expected limits for this region. The skeletons from Alexandropol' sampled in this study a range from $\delta^{18}O_w$ –11.44 to –8.14 ‰, which compares well to the values obtained by Wentz and de Grummond.

Keenleyside et al. (2011) published data obtained from oxygen isotope analysis on 60 human individuals from the Kelfata-Budjaka necropolis associated with the ancient Greek colony of *Apollonia Pontica* (5th – 3rd centuries BC) on the Black Sea coast of Bulgaria. The majority of these individuals fall within the range of $\delta^{18}O_c$ (V-PDB) –7 to –5 ‰ (M1: –5.8 ± 0.7 ‰, M3: –6.1 ± 0.7 ‰). The mean values of the results from Benkovski, Boyanovo and Smyadovo in the present study are significantly less depleted, whereas the mean for the humans from Smyadovo is comparable to the results presented by Keenleyside and colleagues. There are several thousand years in between the two studies, so chronological climate variations in $\delta^{18}O$ might be the best explanation for differences. Furthermore, there is also a significant spatial distance between the sites.

4.4.5.3 *Published modern water values*

Modern $\delta^{18}O_w$ values from the rivers Don, Volga and Kuban are –9.5 ‰, –12.9 ‰, and –11.4 ‰ respectively (Iacumin et al., 2004a, 174). Values of $\delta^{18}O_w$ were obtained from 136 bottled water brands by Bowen (2010). Only two bottled water brands were selected from the study area: The Romanian Izvorul Alb yielded –7.2 ‰ $\delta^{18}O_w$ (n = 1), the Russian Bona yielded –11.4 ‰ $\delta^{18}O_w$ (± 0.03; n = 3). Five samples of water sources around Sozopol at the Bulgarian Black Sea coast averaging –11.1 ± 2.5 ‰ were analysed in the study of Keenleyside et al. (2011), although this seems rather depleted in comparison to $\delta^{18}O$ values in modern precipitation.

4.4.5.4 *$\delta^{18}O$ in precipitation*

In order to compare oxygen isotope values measured in dental tooth enamel carbonate to geographical regions a contour map of the study area was supplemented by $\delta^{18}O_w$ values in modern precipitation obtained from the Online Isotopes in Precipitation Calculator (OIPC; http://wateriso.eas.purdue.edu/waterisotopes/pages/data_access/oipc.html) (Fig. 4.50). Longitudes and latitudes were defined using the website http://www.aw-ew.de/hobby/work.html, the elevation was specified using Google Earth. In the study area, $\delta^{18}O_w$ in modern precipitation is least depleted in the lowlands of Bulgaria, and values above –7 ‰ are only found in this area. The plain opening from the Romanian Danube gives slightly more depleted $\delta^{18}O_w$ values (–7.5 to –7 ‰). The Hungarian Plain also features values between –8 and –7 ‰. No values above –8 ‰ can be found east of Romania and Hungary. While the Balkan Mountains yield oxygen isotope ratios around –8 ‰ and are clearly distinguishable from the surrounding lowlands, values more negative than –9 ‰ can be found in the Apuseni Mountains and even lower than –10 ‰ in the higher areas of the Carpathian Mountain ranges. In the North Pontic area, values around –9 to –8 ‰ in the south decrease to –9.8 to –9 ‰ in central and eastern Ukraine. The $\delta^{18}O_w$ values in the Kuban region are slightly less depleted. In the foothills of the Caucasus Mountains similar oxygen isotope ratios are found to those in the southern Russian steppes. Values decrease to the northeast, where $\delta^{18}O_w$ of around –10 ‰ are found between the rivers Don and Volga and in the area of the Volga mouth. Decreasing $\delta^{18}O_w$ values are shown from the Volga river northward with values of less than –11.5 ‰ in the Samara region. The sampled waters from the Kuban and Volga rivers are conspicuously more depleted than the values from precipitation in the same area. This is caused by depletion in $\delta^{18}O_w$ in big streams with more elevated tributaries. The exact position of the water sample collection along the river course remains uncertain and this should be borne in mind when interpreting the data. In summary, the values from the distinct study regions should theoretically be clearly distinguishable.

To estimate the expected oxygen isotope range for the study area, modern oxygen values in precipitation for elevations of 0 m, 100 m and 300 m above sea level were calculated based on data from the OIPC (Table 4.11). In the Carpathian-Balkan region all sites in Bulgaria showed $\delta^{18}O$ in precipitation water around –6.9 ‰ at the given elevations, though the region around Smyadovo had slightly more depleted values. The Hungarian study sites are situated in an area less than 100 km apart and are all elevated about 80 m to 130 m above sea level. In consequence, the estimated $\delta^{18}O$ values in modern precipitation are rather similar and fall between –7.5 (Kétegyháza) and –8.2 ‰ (Debrecen). Lécolle (1985) measured values below –9.0 ‰ in the Carpathian Basin and values in the mountainous region

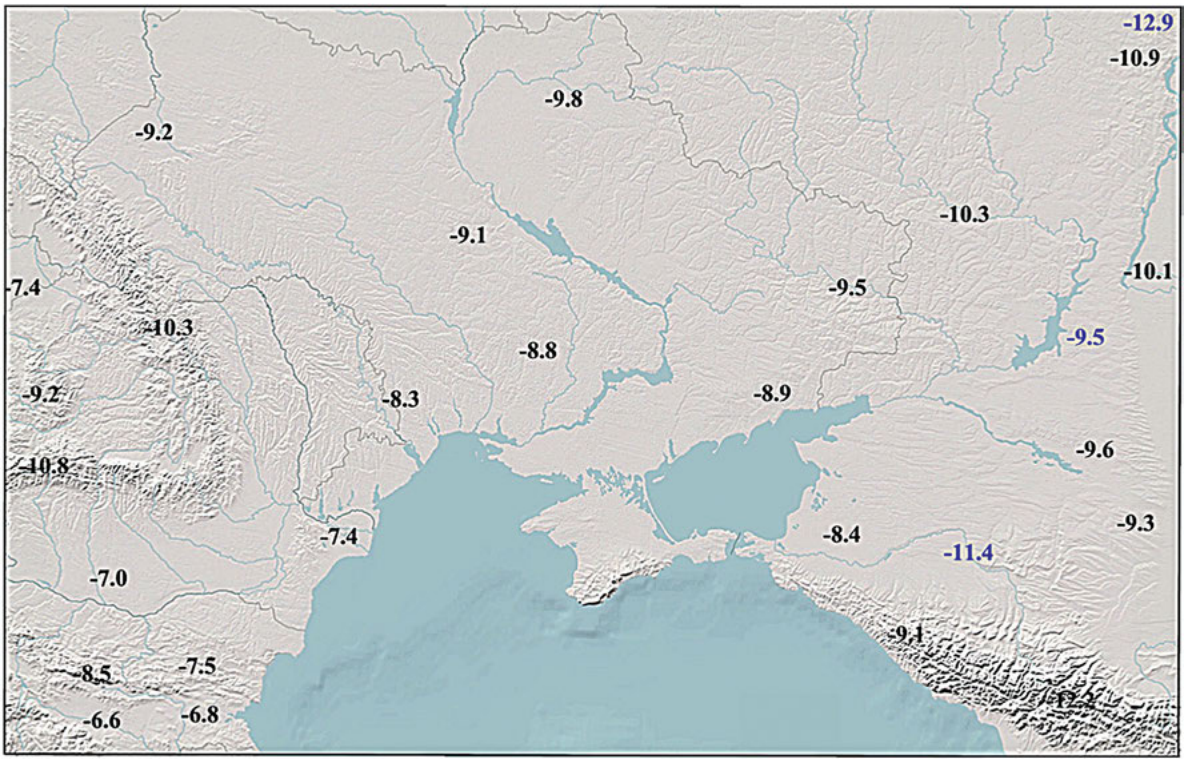


Fig. 4.50 | Contour map of the study area (© D. Bordon) with added $\delta^{18}O_w$ values (black) calculated from the OIPC and water sample values (blue) from the study of Iacumin et al., 2004a, b.

to the east and southeast of the plain would be expected to be even more depleted (Evans et al., 2006, 268). In summary, the expected $\delta^{18}O$ values for the Bulgarian and Hungarian sample sites do not overlap as the Hungarian sites are more inland and more northward and therefore show more depleted oxygen ratios. In the North Pontic region, expected modern oxygen ratios in precipitation range between –8.6 (Vinogradnoe) and –9.8 ‰ (hypothetic 300 m, Nevskoe). Kirovograd, Peshtchanka and Shakhta Stepnaya all average around –9 ‰. Values are generally more depleted than in the Carpathian-Balkan region. Within the North Pontic region, sites give more depleted values along a gradient eastward and inland (northward). The Scythian sites are situated in south Central Ukraine and offer modern oxygen ratios in precipitation between –8.6 ‰ (Ordzhonikidze) and –9 ‰ (Alexandropol'). Due to their same regional location, $\delta^{18}O$ values of Eneolithic/Bronze Age and Scythian samples in the North Pontic region would be expected to be similar. Possible differences might be explained by climatic variations over time and/or differences in diet. The south Russian steppes have approximately the same modern $\delta^{18}O$ values in precipitation as the North Pontic region. The estimated modern oxygen ratio for Olennii is –8.4 ‰, which is situated almost at sea level in the lowlands north of the Caucasian Mountains. The site of Sukhaya Termista II lies about 100 m above sea level and modern oxygen values average at –9.6 ‰. Here again, values tend to become more depleted to the northeast. At the river Volga, modern $\delta^{18}O$ values in precipitation are more depleted. The southernmost site along the Volga, Politotdel'skoe, is situated at 10 to 30 m above sea level. Expected values are around –10.3 ‰. Nikolaevka III, Kalinovka I and Podlesnyi are all located in the outer environs of Samara, where expected values range around –12 ‰. Further east, Berel' in Kazakhstan is located at an elevation of

Table 4.11 | Estimated $\delta^{18}O$ in precipitation at altitudes of 0 m, 100 m and 300 m above sea level at the sampled sites (based on the OIPC). Coordinates for latitude, longitude and elevation at each site are also included.

site	coordinates (decimal degrees)		$\delta^{18}O$ in modern precipitation (‰) at altitude above sea level:			elevation at site
	latitude	longitude	0 m	100 m	300 m	
Ovchartsi	42.19775	26.04652	–6.4	–6.6	–7.0	150 m
Boyanovo	42.26361	26.61334	–6.5	–6.7	–7.1	150 m (village)
Smyadovo	43.05255	26.99511	–6.7	–6.9	–7.3	100 m (village)
Benkovski	42.40901	25.90180	–6.5	–6.7	–7.1	130 m (village)
Sárrétudvari	47.24565	21.18783	–7.7	–7.9	–8.2	80 m
Kétegyháza	46.54162	21.18336	–7.4	–7.6	–8.0	90 m
Debrecen	47.52532	21.63174	–7.8	–8.0	–8.3	100 to 130 m
Balmazújváros	47.60801	21.34163	–7.8	–8.0	–8.4	80 to 100 m
Dévaványa	47.03082	20.95367	–7.6	–7.8	–8.2	80 m
Püspokladány	47.31509	21.11744	–7.7	–7.9	–8.3	80 m
Vinogradnoe	47.20505	35.55965	–8.6	–8.7	–9.1	26 to 100 m
Kirovograd	48.51422	32.19543	–8.7	–8.9	–9.2	150 m
Peshtchanka	48.59994	35.31237	–8.9	–9.1	–9.5	60 m
Shakhta Stepnaya	48.38304	36.37159	–8.9	–9.1	–9.5	100 to 150 m
Nevskoe	49.17010	37.97648	–9.2	–9.4	–9.8	?
Olennii	45.60026	38.53038	–8.4	–8.6	–9.0	3 m
Sukhaya Termista II	46.56592	43.66310	–9.4	–9.6	–10.0	100 m
Nikolaevka III	53.09154	50.31464	–11.6	–11.8	–12.2	40 to 70 m
Kalinovka I	53.83378	51.28899	–12.0	–12.2	–12.6	60 to 80 m
Politotdel'skoe	49.76372	45.39928	–10.3	–10.5	–10.8	10 to 30 m
Podlesnyi	53.23150	50.50381	–11.7	–11.9	–12.3	30 (to 70) m
Alexandropol'	48.01403	34.44318	–8.7	–8.9	–9.3	140 m
Ordzhonikidze	47.66028	34.06208	–8.6	–8.8	–9.1	80 m
Drana Kokhta	47.80251	33.88670	–8.6	–8.8	–9.2	95 m
Zolotaya Balka	47.37868	33.96404	–8.5	–8.7	–9.1	80 m
Babina Mogila	47.81360	33.93832	–8.6	–8.8	–9.2	95 m
Berel'	49.34361	86.36522	1000 m: -14.2	1500 m: -15.2	2000 m: -16.2	ca. 1100 m

about 1100 m. Modern oxygen ratios average at about –14.4 ‰. This much depleted value is due to the site's latitude but also to its altitude, due to the decrease of approximately 0.26 ‰ per 100 m in altitude (Poage/Chamberlain, 2001).

4.4.5.5 Conversion of $\delta^{18}O$ in tooth enamel carbonate into $\delta^{18}O$ in water

As discussed in chapter 4.4.1.4, there is a set of equations to convert $\delta^{18}O$ from tooth enamel carbonate into phosphate and into water. For humans the most frequently used are the fractionation equations of Longinelli (1984), Luz et al. (1984), Levinson et al. (1987), Daux et al. (2008), Pollard et al. (2011a) and Chenery et al. (2012). The results using each of these equations are presented in Appendix C Table 1.

The conversion of $\delta^{18}O_c$ (V-PDB) to $\delta^{18}O_w$ is under serious discussion, however, as the magnitude of error increases with each step of the conversion and can be up to ± 3.5 ‰ (cf. Pollard et al., 2011a; Chenery et al., 2012). The regression equations by Longinelli (1984), Luz et al. (1984) and Levinson et al. (1987) are based on very small sample sets. Daux et al. (2008) and later Pollard et al. (2011a) combined and enlarged the data set to 94 samples but even their equation increases the variability of a single population from ± 1 ‰ to ± 2.5 ‰ (Pollard et al., 2011a). It brings into question the quality of the correlation between $\delta^{18}O$ in phosphate and surface water as well as between $\delta^{18}O$ in carbonate and phosphate. Given the fact that the $\delta^{18}O$ variability in the study area is limited due to similar ecology and temperature, this variability in magnitude is rather crucial.

Differences between the fractionation equations are shown in Appendix C Table 1. Using the Bulgarian samples as an example, the most depleted $\delta^{18}O$ values result from using Longinelli's (1984) equation. Slightly less depleted results are given using the equation used by Luz et al. (1984) and much less depleted results are given by the equation used by Levinson et al. (1987). The largest differences appear between the Longinelli, Luz and Daux equations on one hand and the Levinson equation on the other hand. Chenery et al. (2010) argued that the Levinson equation is the best match for samples from the British Isles. In respect to this study, and when compared to the expected local range of $\delta^{18}O$ values, estimated using the OIPC, the worst match for $\delta^{18}O$ values of above –9 ‰ is given by the equation established by Levinson and colleagues (1987), and below –9 ‰ by the equation used by Luz et al. (1984). Longinelli's equation (as given in Daux et al., 2008) is the best match for the results of this study.

Different fractionation equations for the conversion of $\delta^{18}O$ in phosphate (V-SMOW) to $\delta^{18}O$ in water are known for horses as well and are shown in Appendix C Table 2. Subject to the study region and species studied, the equations yield varying linear results. Bryant et al. (1994) analysed equid teeth (*Equus burchelli*, *Equus caballus*, *Equus zebra*) from North America and East Africa and yielded a wide scatter of results. Delgado Huertas et al. (1995, 4303) assume that the combination of two faunal species with different migratory behaviours in combination with two largely varying ecological regions lead to the wide scattering. In 1994 Sánchez Chillón and colleagues published their data on *Equus przewalskii*, *Equus caballus* and *Equus asinus*. Delgado Huertas et al. (1995) enlarged this data set with new data from Argentinean horses and revised the equation.

When the three fractionation equations are applied to the horse sampled from Berel', the results are very similar when the Sánchez Chillón and the Delgado Huertas equations are applied, whereas the values gained from using the Bryant equation are much more depleted. Though the Bryant et al. (1994) equation is the best match for our data, we applied the equation by Delgado Huertas et al. (1995) due to the wider scatter of the Bryant values.

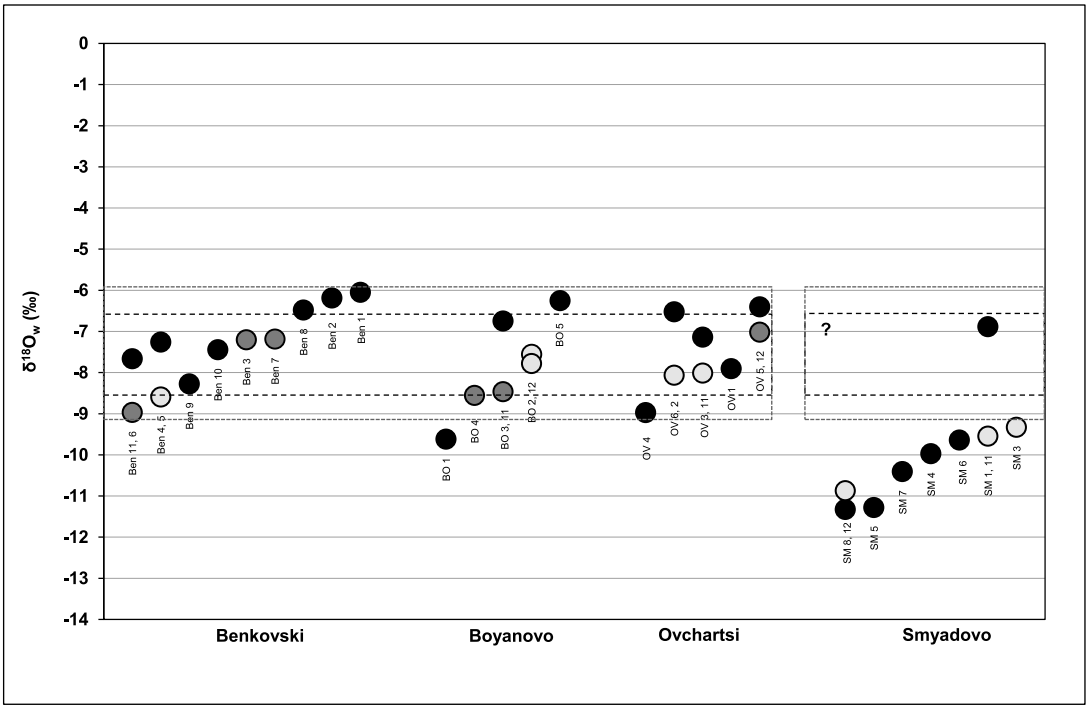


Fig. 4.51 | $\delta^{18}O_w$ values (using Longinelli, 1984) for the four Bulgarian sites sampled: First molars (black symbols), second molars (light grey), third molars (dark grey). Results from teeth taken from the same individuals are shown in a line. 'Local' $\delta^{18}O_w$ ranges (mean ± 1 ‰ and 1.6 ‰) are marked by a line.

4.4.6 'Locals' and 'non-locals'

4.4.6.1 Results of the data conversion into $\delta^{18}O$ in water and 'local' $\delta^{18}O$ ranges

4.4.6.1.1 Eneolithic and Bronze Age

Bulgaria

As discussed above, the equation used by Longinelli (1984) offers the best results and will therefore be applied in the following paragraph. In total, the $\delta^{18}O_w$ values for the Bulgarian samples show a wide range between –11.33 and –6.05 ‰ (Fig. 4.51). Three of the sites are located at comparable latitudes and distance from the ocean. The $\delta^{18}O_w$ values of the nine humans from Benkovski vary between –8.97 and –6.05 ‰ with a mean of –7.39 ± 0.95 ‰. The mean $\delta^{18}O_w$ of –7.85 ± 1.14 ‰ and the range from –9.62 to –6.25 ‰ for the seven samples of five individuals from Boyanovo compares well to values from Benkovski and Ovchartsi, where the average $\delta^{18}O_w$ value is –7.50 ± 0.88 ‰. The range from –8.97 to –7.02 ‰ for the five human skeletons, on the other hand, is more limited. The site of Smyadovo is located further to the north and yielded more depleted $\delta^{18}O_w$ values between –11.33 and –6.89 ‰. The highest value came from an outlier, which had a value similar to those from the other Bulgarian sites. The $\delta^{18}O_w$ mean –9.92 ± 1.36 ‰ is much more depleted, however, than the averages of the other sites.

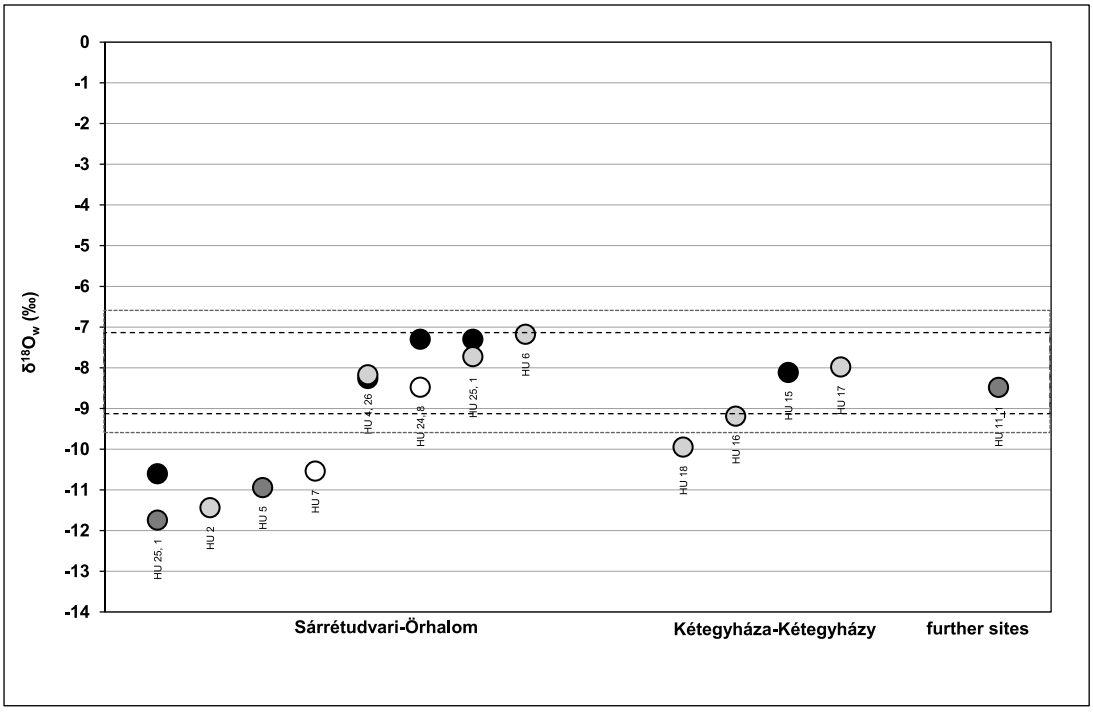


Fig. 4.52 | $\delta^{18}O_w$ values (using Longinelli, 1984) for the sites Sárretudvari-Őrhalom, Debrecen-Dunahalom, Kétegyháza-Kétegyházi in the Eastern Hungarian Plain: First molars (black symbols), second molars (light grey), third molars (dark grey) and second premolars (white). Results from teeth taken from the same individuals are shown in a line. 'Local' $\delta^{18}O_w$ ranges (mean ± 1 ‰ and 1.6 ‰) are marked by a line.

As discussed above, a modified version of Vohberger's (2011) approach to establish the local $\delta^{18}O_w$ range was applied. The average values of all the Bulgarian sites except Smyadovo cluster together with a combined $\delta^{18}O_w$ mean of –7.55 ± 0.96 ‰. Smyadovo is excluded because values were too depleted to be of 'local' origin. The OIPC shows $\delta^{18}O_w$ in modern precipitation around –6.8 ‰ for all sites, which is an acceptable divergence. On this basis, a local $\delta^{18}O_w$ range for all Bulgarian sites between –8.55 and –6.55 ‰ or rather –9.15 to –5.99 ‰ is estimated when accounting for a 1.6 ‰ error. The more limited 'local' $\delta^{18}O_w$ range highlights five data points from Benkovski (Ben 1, 2, 6, barely Ben 5, 8), three from Boyanovo (Bo 1, 5, barely Bo 4) and two from Ovchartsi (Ov 4, 5, barely Ov 6) as outliers. There is only one outlier (Bo 1) from the wider range. All but one of the results from Smyadovo (Sm 1) can be considered as outliers. As Smyadovo is the only Eneolithic site the results suggest climatic differences or foreign origins to be the reason for the more depleted values, which will be discussed in more detail in chapter 4.5.1.

Hungary

The eight individuals from Sárrétudvari-Őrhalom, the skeleton from Debrecen-Dunahalom and the four sampled individuals from Kétegyháza-Kétegyházi tanyák in the East Hungarian Plain yield a range from $\delta^{18}O_w$ –11.75 to –7.18 ‰ and an average value of –9.03 ± 1.53 ‰ (Fig. 4.52). This rather low mean can be explained by the fact that four of the individuals from Sárrétudvari with $\delta^{18}O_w$ values below –10 ‰. These values are too depleted for the Eastern Hungarian Plain and below the range that might be considered as 'local'. Excluding these four individuals, the mean value was –7.78 ± 0.53 ‰, which is a

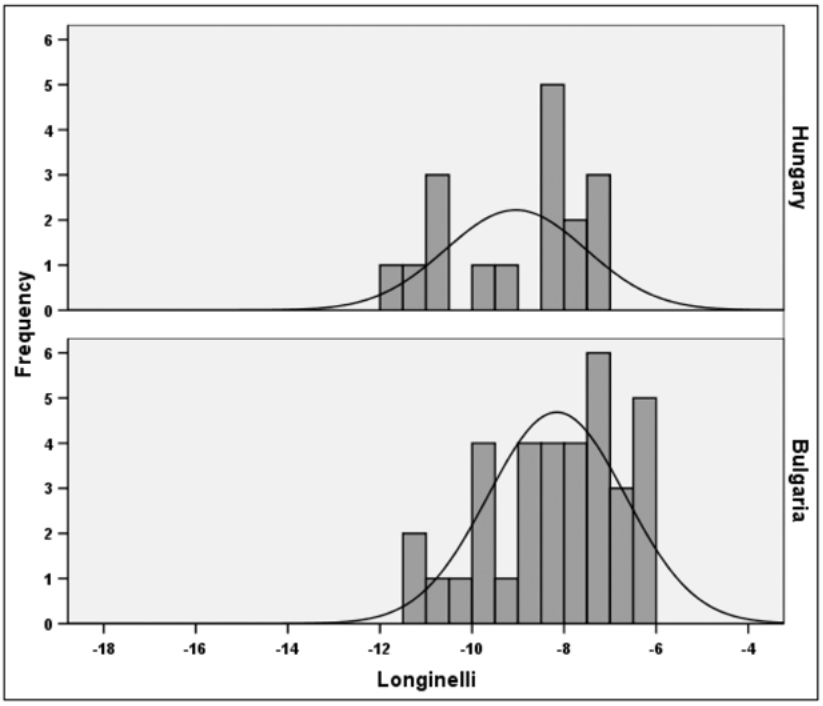


Fig. 4.53 | Histograms of the distribution of the $\delta^{18}O_w$ values of the Hungarian and Bulgarian samples.

more probable reading for that area. Considering a 'local' $\delta^{18}O_w$ of –9.15 to –7.15 ‰ (or –9.74 to –6.56 ‰), five samples deriving from four individuals from Sárrétudvari (HU 1, 2, 5, 7, 25) and one individual from Kétegyháza (HU 18) are outliers.

The histograms (Fig. 4.53) show the distribution of the $\delta^{18}O_w$ values of the Hungarian and Bulgarian individuals. When the sites are summarized to the regions Hungary and Bulgaria, the values generally follow a normal distribution curve. The Hungarian curve is rather flattened and the distribution is obviously not consistent. This is slightly better for the Bulgarian sites.

Ukraine

The five individuals from the kurgan Sugokleya in the Ukrainian city of Kirovograd offer $\delta^{18}O_w$ values from –12.04 ‰ to –8.16 ‰ with a mean value of –9.31 ± 1.19 ‰ (Fig. 4.54). At Vinogradnoe kurgans 3 and 24, eleven humans sampled singularly and five individuals sampled twice gave an average value of –8.94 ± 1.21 ‰ and a wide range of values between –11.15 and –6.55 ‰. The results for Peshtchanka show very inconsistent values ranging from –13.00 to –7.41 ‰. The mean value for this site is –9.61 ± 1.77 ‰. Ignoring grave 14 the mean of 8.91 ± 1.44 ‰ was significantly less depleted. The mean for Shakhta Stepnaya is –8.90 ± 0.64 ‰ with a range of oxygen ratios from –9.90 to –8.11 ‰. The means of the last three sites are very similar. The $\delta^{18}O_w$ values for Nevskoe are slightly more depleted. In contrast to the four sites in the characteristic steppe environment of southern Central Ukraine, the site is located futher to the east, where one would expect to get slightly more depleted results. However, one outlier (OU 4) shows an unexpectedly high value of –7.06 ‰. The remaining four values range from

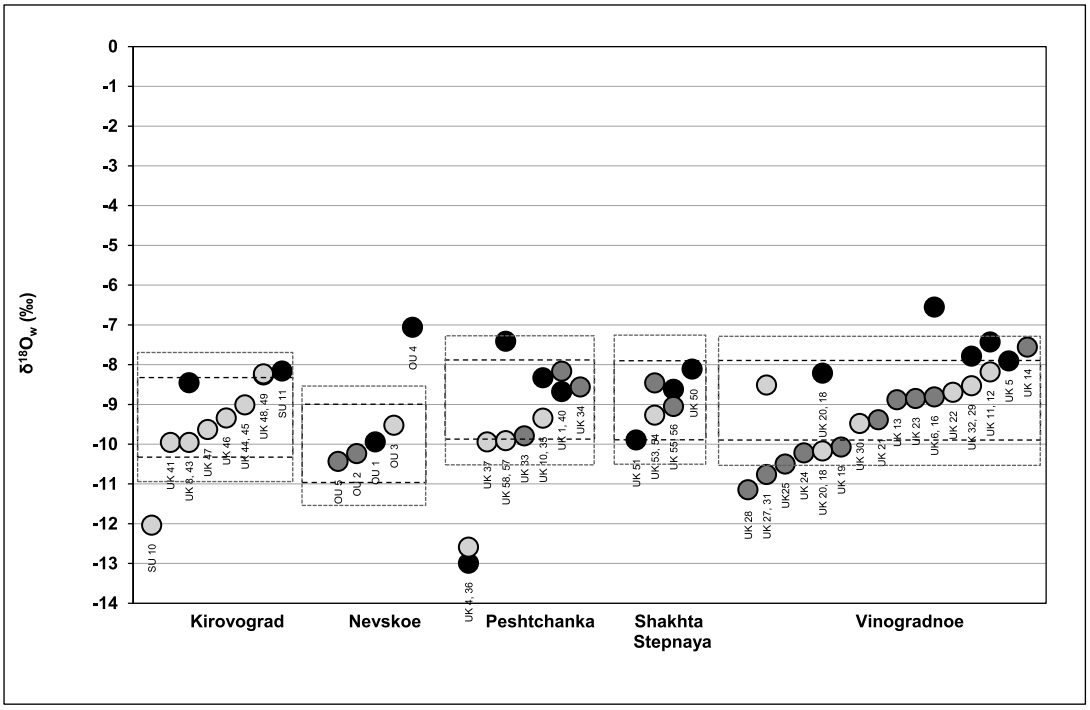


Fig. 4.54 | $\delta^{18}O_w$ values for the five Ukrainian sites sampled: First molars (black symbols), second molars (light grey) and third molars (dark grey). Results from teeth taken from the same individuals are shown in a line. 'Local' $\delta^{18}O_w$ ranges (mean ± 1 ‰ and 1.6 ‰) are marked by a line.

–10.43 to –9.63 ‰ with a mean of –10.04 ± 0.39 ‰. Including the outlier the mean (–9.44 ± 1.37 ‰) is still more depleted than the average values of the other Ukrainian sites.

In summary, the average oxygen isotope ratio for all Ukranian sites under investigation is –9.19 ± 1.29 ‰. The expected and estimated 'local' $\delta^{18}O_w$ ranges for Vinogradnoe, Peshtchanka and Shakhta Stepnaya are, due to their spatial proximity, very similar (approximately between –10.5 and –7 ‰) and the range for Kirovograd is not very different either. Adopting the more constrained 'local' range shows 10 outliers in Vinogradnoe (UK 6, 11, 14, 18, 19, 24, 25, 28, 29, 31), four in Peshtchanka (UK 4, 36, 37, 58) and none in Shakhta Stepnaya. Four outliers (SU 10, SU 11, UK 48, UK 49) are seen in Kirovograd. There is only one outlier (OU 4) in Nevskoe. Adopting the wider range reduces the number of outliers to three in Vinogradnoe (UK 6, 28, 31), two in Peshtchanka (UK 4, 36), one in Kirovograd (SU 10) and one in Nevskoe (OU 4). The $\delta^{18}O_w$ values of the North Pontic individuals broadly follow a normal distribution curve. However, the outlier individual from Peshtchanka is clearly at variance from the curve.

Volga region

The $\delta^{18}O_w$ values from the three sites in the vicinity of Samara in Russia give more depleted results (mean –11.15 ± 1.06 ‰) than the fourth site at the river Volga, Politotdel'skoe with an average of –9.43 ± 0.99 ‰ (Fig. 4.55). Kalinovka I (with a mean value of –11.33 ± 1.21 ‰), Nikolaevka III (with an average of –11.12 ± 0.71 ‰) and Podlesnyi (with a mean of –11.09 ± 1.80 ‰) show very similar results. The range of the sites in the Samara region yield oxygen values between –13.47 and –9.14 ‰, but most of the values are between ~ –12 and ~ –10 ‰. Politotdel'skoe shows values between –10.34 and –8.38 ‰. The

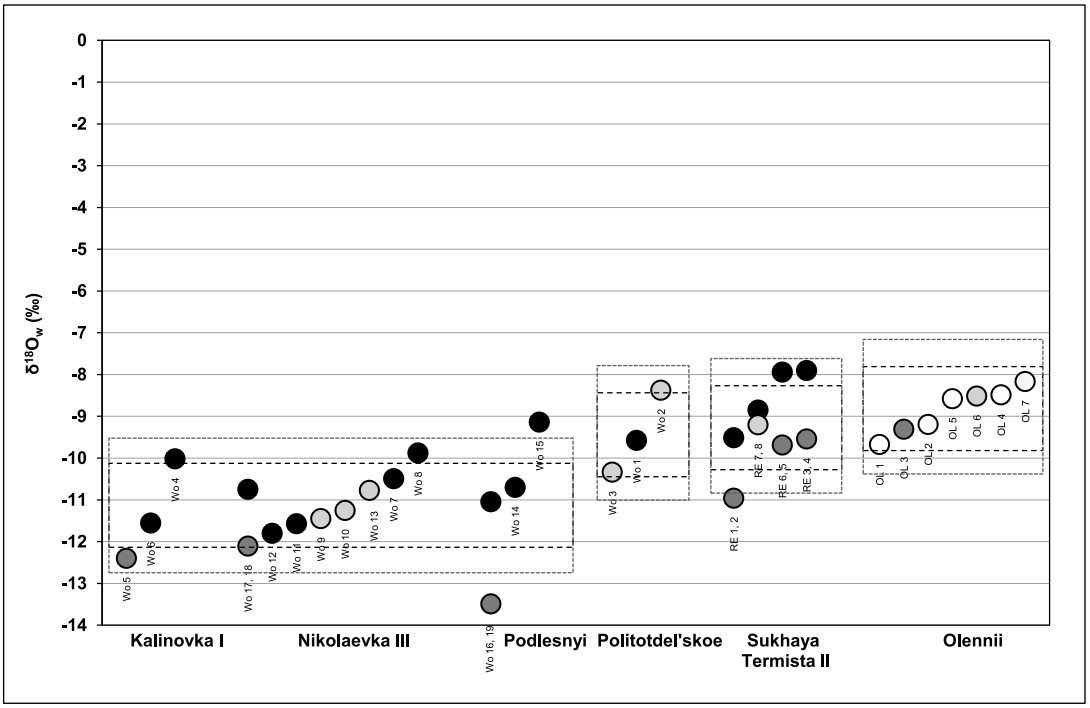


Fig. 4.55 | $\delta^{18}O_w$ values for the four sites in the Volga region, for Sukhaya Termista II and for Olennii in the Kuban region: First molars (black symbols), second molars (light grey), third molars (dark grey). White circles symbolize second deciduous molars and canines. Results from teeth taken from the same individuals are shown in a line. 'Local' $\delta^{18}O_w$ ranges (mean ± 1 ‰ and 1.6 ‰) are marked by a line.

value for $\delta^{18}O$ in modern precipitation lies at the lower margin of this range at approximately –10.4 ‰ in Politotdel'skoe and approximately –12 ‰ in the Samara region. Modern water samples from the river Volga are even more depleted. In general, however, the majority of the analyses fall within the expected 'local' $\delta^{18}O_w$ range of the Samara region of –12.15 to –10.15 ‰ or –12.74 to –9.56 ‰ respectively. Five samples (Wo 4, 5, 8, 15 and 19) are outliers from the more constrained range and only two (Wo 15 and 19) lie outside the wider range. In Politotdel'skoe, sample Wo 2 is a potential outlier. The results from the Volga sites broadly agree with a normal distribution pattern.

South Russia

The site of Sukhaya Termista II has an average $\delta^{18}O_w$ value of –9.20 ± 0.99 ‰ and a range from –10.96 to –7.91 ‰ (Fig. 4.55). All four individuals were sampled in duplicate. All second sampled teeth gave lower $\delta^{18}O_w$ values than the first ones. The OIPC annual $\delta^{18}O_w$ in precipitation average of –9.60 ‰ fits the results very well. The more constrained range has three outliers, RE 2, 3 and 6, whereas only RE 2 lies at the lower margin of the wider range. The oxygen isotope ratios for Olennii also cluster between –9.68 and –8.17 ‰, though the site lies a little to the southwest. The average oxygen isotope ratio for this site is marginally more enriched (–8.85 ± 0.55 ‰). Again, this forms a good match with the OIPC annual $\delta^{18}O_w$ in precipitation average of –8.40 ‰. There is no outlier from the estimated 'local' $\delta^{18}O_w$ range of human $\delta^{18}O_w$ mean plus or minus a 1 ‰ standard deviation. The studies in Sukhaya Termista II and Olennii are based on very small sample sizes; hence the distributions of the $\delta^{18}O_w$ values are not diagnostically conclusive.

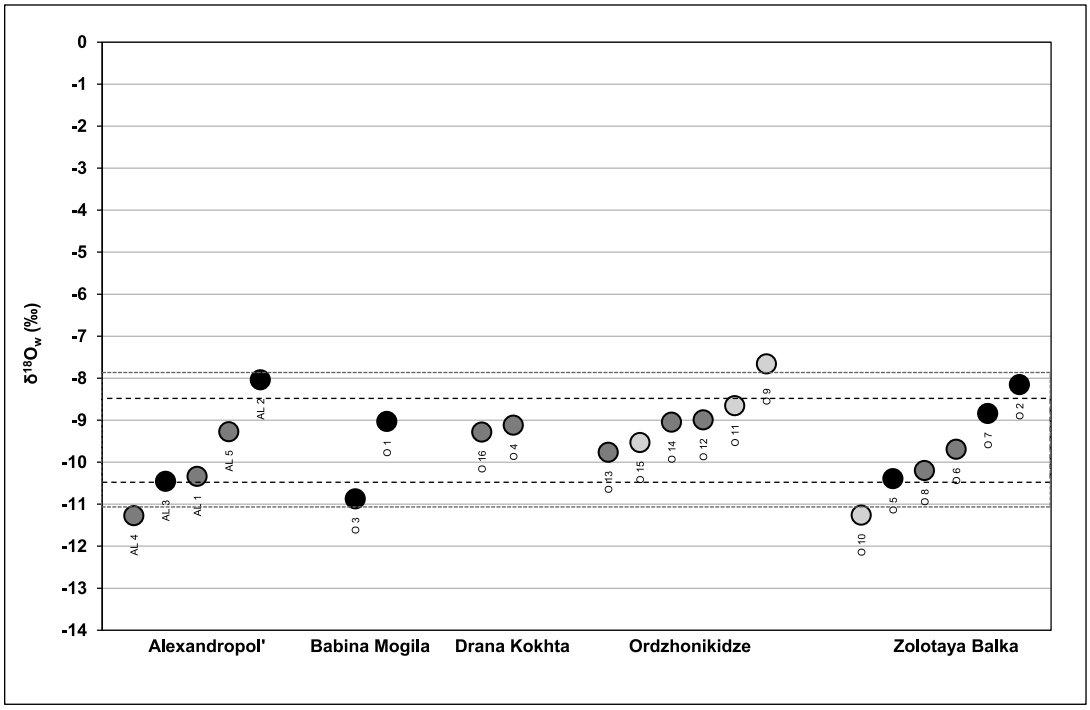


Fig. 4.56 | $\delta^{18}O_w$ values for the five sites of the Scythian period in the North Pontic region: First molars (black symbols), second molars (light grey), third molars (dark grey). Results from teeth taken from the same individuals are shown in a line. 'Local' $\delta^{18}O_w$ ranges (mean ± 1 ‰ and 1.6 ‰) are marked by a line.

4.4.6.1.2 Iron Age

North Pontic region

The Northern Pontic samples as a whole (Fig. 4.56) had an average $\delta^{18}O_w$ of –9.52 ± 1.01 ‰ with the most depleted value being –11.27 ‰ (AL 4, Alexandropol') and the least depleted value being –7.66 ‰ (O9, Ordzhonikidze). Individually, the five human skeletons from Alexandropol' yielded values between –11.27 ‰ and –8.04 ‰. The average for this site was –9.88 ± 1.25 ‰. The two individuals from Babina Mogila had a mean of –9.95 ‰, the two skeletons from Drana Kokhta had a mean of –9.20 ‰. Six individuals were sampled at both Zolotaya Balka and Ordzhonikidze. Individuals from the first site had a wide range from –11.26 to –8.16 ‰ and a mean value of –9.76 ± 1.12 ‰. Skeletons from the second site had a range from –9.77 to –7.66 ‰ and a mean of –8.94 ± 0.74 ‰. Results from oxygen isotope analysis given here were significantly lower than the OIPC annual $\delta^{18}O_w$ mean of approximately –8.8 ‰. On the basis of the proximity of the sites, a 'local' $\delta^{18}O_w$ range of –10.5 to –8.5 ‰ (–11.1 to –7.9 ‰, respectively) was estimated. Several individuals fell outside this range: AL 2, 4, O 2, 3, 9 and 10 lay outside the narrower frame, whereas AL 4, O 9 and 10 lay outside the wider frame.

Berel' (Kazakhstan)

The human individuals from Berel' had a mean of –15.74 ± 1.40 ‰ (Fig. 4.57). The most depleted value was –17.40 ‰ (Be 5), the least depleted was –12.90 ‰ (Be 11). The five horse teeth were sampled vertically, at the top and bottom of the section. The values ranged between –18.24 ‰ and –13.92 ‰ with a

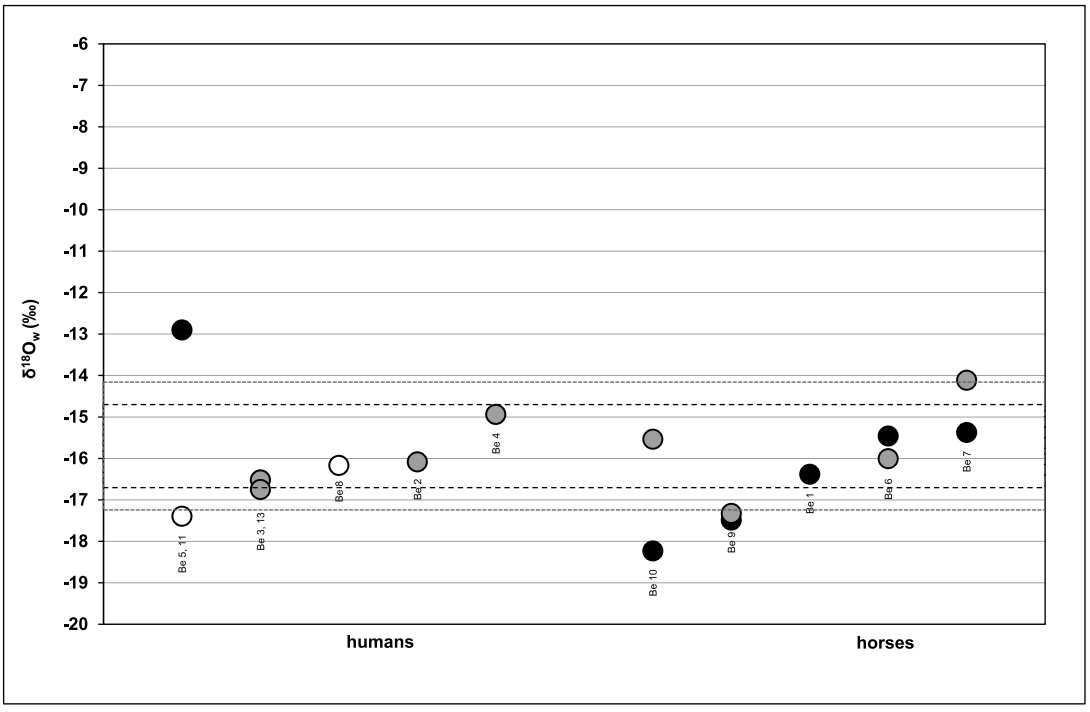


Fig. 4.57 | $\delta^{18}O$ values (using Delgado Huertas et al. 1995 for horses) for Berel' (Altai Mountains): First molars (black symbols), second molars (light grey), third molars (dark grey). White circles symbolize first premolars and incisors. Results from teeth taken from the same individuals are shown in a line. Horses were sampled at the cusp (black symbols) and cervix (grey symbols). 'Local' $\delta^{18}O_w$ ranges (mean ± 1 ‰ and 1.6 ‰) are marked by a line.

mean of –15.68 ± 1.37 ‰ using the equation of Delgado Huertas et al. (1995). Only Be 10 showed a large variation between top and bottom tooth sections. The 'local' range is from –16.7 to –14.7 ‰ or from –17.3 to –14.1 ‰ respectively. This is more depleted than the OIPC $\delta^{18}O$ value given for the site (–14.4 ‰). Due to site location, water sources might be fed by smaller mountain rivers and melt waters, which makes the $\delta^{18}O$ in drinking water significantly more depleted than that of precipitation. If the narrower 'local' range is accepted, Be 5 and potentially Be 13 are human outliers. Be 11 lies far outside the range that can be regarded as 'local'. Be 7 cervix, Be 9 and Be 10 cusp are the horse teeth, which are outside the 'local' range, maybe due to their seasonal signal. In total, the results from the horses were similar to those from the human samples suggesting that both humans and horses lived in areas with a similar climate.

4.4.6.2 Potential correlation between $\delta^{18}O$ results and longitude and latitude

Figure 4.58 demonstrates that there is only a weak correlation between $\delta^{18}O_w$ values and geographical location. R^2 for the negative linear regression between $\delta^{18}O_w$ and latitude is 0.29, while r^2 for $\delta^{18}O_w$ and longitude is 0.21. Despite these results a general trend between less depleted $\delta^{18}O_w$ in Bulgaria and more depleted values in the Volga region can clearly be distinguished.

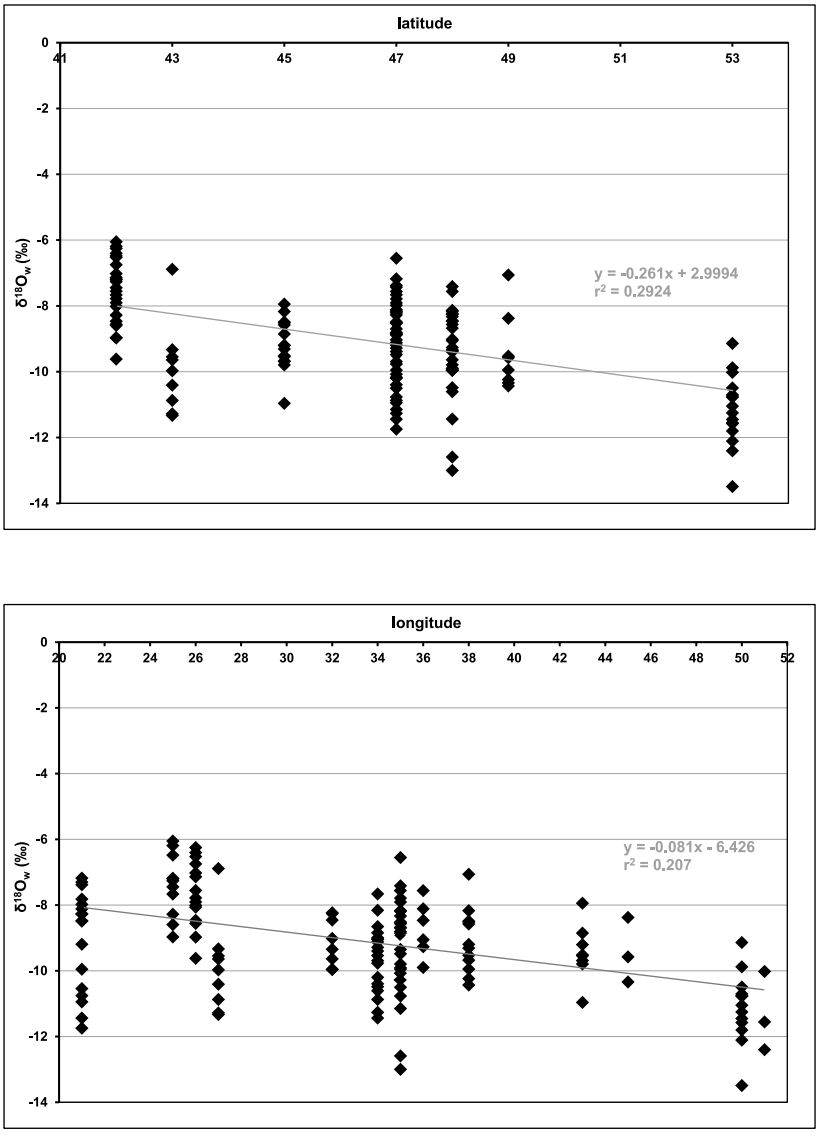


Fig. 4.58 | Linear regression lines for $\delta^{18}O_w$ values and latitude and longitude (from Bulgaria to the Volga region).

4.4.6.3 Evaluation of the 'local' $\delta^{18}O$ values

In total, there are 66 outlier values that show 'non-local' $\delta^{18}O_w$ values when adopting the narrower range and 31 outlier values when adopting the wider range. Since second samples were taken from a number of human individuals, these numbers do not reflect the actual number of 'non-local' individuals, but of 'non-local' analysis results. The numbers of outlier individuals are not linked to the sample sizes at each site since there is a very weak correlation ($p = 0.16$ for the narrow $\delta^{18}O_w$ range; $p = 0.12$ for the wide $\delta^{18}O_w$ range; Pearson's correlation). Table 4.12 shows the percentages of 'non-local' $\delta^{18}O_w$ values at each sample site. The narrow 'local' $\delta^{18}O_w$ ranges present a percentage of outliers that is probably a little too

Table 4.12 | Percentages of outlier $\delta^{18}O_w$ values of the sample sites and regions.

site	narrow $\delta^{18}O_w$ range (%)	wide $\delta^{18}O_w$ range (%)
Eneolithic and Bronze Age		
Benkovski	45	–
Boyanovo	43	14
Ovchartsi	33	–
Smyadovo	89	89
Hungary	35	35
Kirovograd	40	7
Nevskoe	20	20
Peshtchanka	36	21
Shakhta Stepnaya	–	–
Vinogradnoe	48	12
Volga: Samara region	31	13
Volga: Politotdel'skoe	33	–
Olennii	–	–
Sukhaya Termista II	38	13
Iron Age		
North Pontic	29	14
Bereĺ	38	29

high, whereas the wider ranges present much lower incidences of outliers. The very high percentage of 89 % outlier values in Smyadovo could be linked to the evaluation of the 'local' $\delta^{18}O$ by combining the mean of all the Bulgarian samples. Pellegrini et al. (2008, 1716) propose the interpretation of oxygen isotope compositions on a site-by-site basis in order to include site specific variables that could affect the 'local' range. The results for Smyadovo, however, are extremely depleted making it improbable that it reflects 'local' oxygen ratios.

4.5 Combined results and discussion of $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses

4.5.1 Eneolithic and Bronze Age

Bulgaria

The biologically available $^{87}Sr/^{86}Sr$ at Benkovski ranges from 0.7075 to 0.7087 (20), while the expected $\delta^{18}O_w$ range for the area where the Bulgarian sites are located is between –8.55 and –6.55 ‰ (mean ± 1 ‰) or –9.15 and –5.95 ‰ (mean ± 1.6 ‰)[1] (Fig. 4.59). The $^{87}Sr/^{86}Sr$ values for all the humans except

1 A mean ± 1 ‰ and a ± 1.6 ‰ range will also be given in the following data; for the explanation for using these ranges see Chapter 4.4.5.

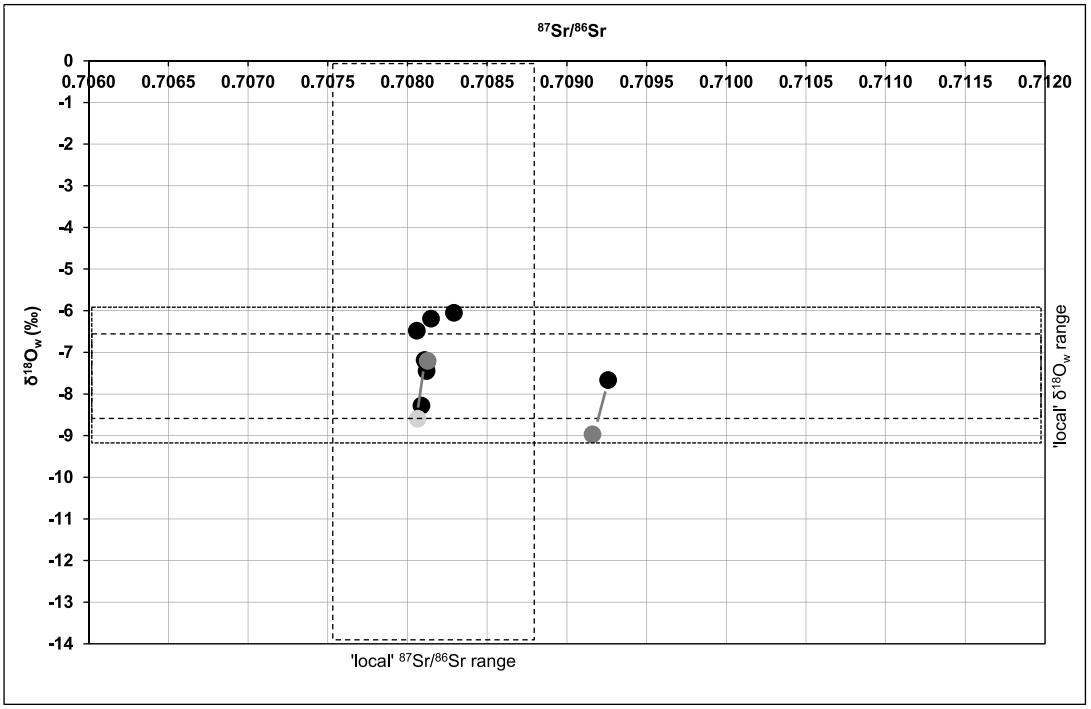


Fig. 4.59 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Benkovski: First molars (black circles), second molars (dark grey circles), third molars (light grey circles). Grey lines link teeth analysed from the same individual. Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

burial 3 in mound 2 (skeleton 2.3)[2] lie within the expected 'local' strontium signature range. The oxygen analyses give similar results in that none of the sampled skeletons is 'non-local', though the second molar from grave 2.3 and three further humans, kurgan 1 burials 2 and 3 and kurgan 2 burial 6, lie within the limits of the wider $\delta^{18}O_w$ range rather than the more restricted one.

Considering the differences of graves 1.2, 1.3 and 2.6 to be minor, only skeleton 2.3 evidently differs in its $^{87}Sr/^{86}Sr$ signal. There is no change when the two samples are added to one mean value. Burial 3 in burial mound 2 refers to an Early Bronze Age single burial of a juvenile, probably male, skeleton in supine position and southwest-northeast orientation, which was buried with crouched legs in a rectangular burial pit. The burial differs neither archaeologically nor anthropologically from the remaining sampled graves in the mound, although it was the only grave that contained one pottery fragment. Figure 4.65 shows a geological map and estimated $^{87}Sr/^{86}Sr$ values on the basis of the geology and $\delta^{18}O_w$ values based on OIPC calculations. The elevated $^{87}Sr/^{86}Sr$ values of the first and second molars from skeleton 2.3 reflect the local Cenozoic geology, but do not lie within the estimated range of 'locally' bioavailable Sr. The $^{87}Sr/^{86}Sr$ values of the samples from the other skeletons suggest a common place of origin or childhood-residence with a Mesozoic $^{87}Sr/^{86}Sr$ signal. The closest Mesozoic rocks occur less than 15 km away. As mentioned above, the local geology does not seem to be reflected in the $^{87}Sr/^{86}Sr$ values from the reference materials, which indicates that the biologically available Sr at this site does not agree with what would be expected from the geology. The spread in $\delta^{18}O_w$ values might also suggest different

2 Burial mound 2 burial 3 = 2.3. This form of abbreviation will be maintained in the following.

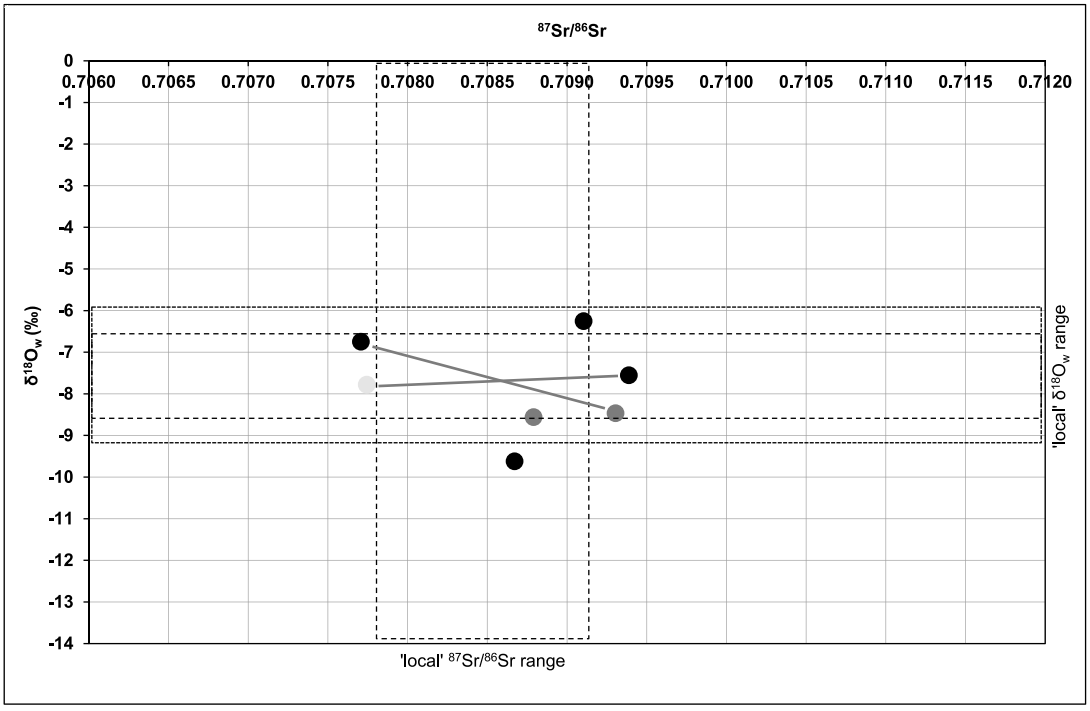


Fig. 4.60 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Boyanovo: First molars (black circles), second molars (dark grey circles), third molars (light grey circles). Grey lines link teeth analysed from the same individual. Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

sources of water supply. The majority of the $\delta^{18}O_w$ results are more depleted than the OIPC data would suggest. The enriched $\delta^{18}O_w$ values of burials 2 and 3 in kurgan 1 and burial 6 in kurgan 2 could also be explained by a possible enrichment in the first molars due to breastfeeding. Double analysis of two teeth per individual was performed for burial 2 in burial mound 1, where a first and a third molar were analysed, and for burial 3 in kurgan 2, where a first and a second molar were sampled. Similar $^{87}Sr/^{86}Sr$ ratios associated with varying $\delta^{18}O$ values hint at an influence from breastfeeding, although a possible change of residence between regions of similar geology but varying climate sometime between early and later childhood cannot be excluded.

At the site of Boyanovo the estimated 'local' $^{87}Sr/^{86}Sr$ signature ranges from 0.7078 to 0.7091 (2σ) and the $\delta^{18}O_w$ span lies between –8.55 and –6.55 ‰ (mean ± 1 ‰) or –9.15 and –5.95 ‰ (mean ± 1.6 ‰) (Fig. 4.60). Even though these ranges are rather wide, only one of the tooth enamel samples (burial 46) lies within the more narrow 'local' range. The majority of the $\delta^{18}O_w$ values are more depleted than –7 ‰, and although the results from graves 5 and 6 and grave 14, skeleton 2, fall outside the narrow $\delta^{18}O_w$ range, the differences are minor. Grave 5 falls outside the broader $\delta^{18}O_w$ range and can be considered the most probable outlier. Grave 5 is not archaeologically different from the other Yamnaya graves, which show common features like wooden covers, skeletons in supine position with crouched legs and ochre colouring. Though four data points, graves 4 and 14, do not lie within the 'local' $^{87}Sr/^{86}Sr$ range, differences are minor. All results roughly correspond with the Mesozoic geology in the vicinity of the site (Fig. 4.65). Where two teeth were sampled from the same individual, the resultant variation in values can be found at locations within a 5 km radius around the site. Two skeletons from the Boyanovo kurgan were sampled for M1 and M2 (grave 4) and M1 and M3 (grave 14). They vary significantly in their

$^{87}Sr/^{86}Sr$ values. The large intra-individual variations suggest changes of residence with different geology but similar climatic conditions between early and later childhood and inter-individual variations suggest different places of origin for the individuals buried in this kurgan.

The 'local' $^{87}Sr/^{86}Sr$ signature for the site of Ovchartsi ranges from 0.7076 to 0.7113 (2σ) including the sediment sample or from 0.7097 to 0.7101 (2σ) excluding it (Fig. 4.61). Again, the $\delta^{18}O_w$ range of the Bulgarian sites stretches from –8.55 to –6.55 ‰ or from –9.15 to –5.95 ‰ (mean ± 1 ‰ or 1.59 ‰ respectively). While five teeth from three human individuals, burials 1, 9 (M1) and 15 skull west in the Big Tumulus, yield $^{87}Sr/^{86}Sr$ results below the narrower 'local' $^{87}Sr/^{86}Sr$ range, all samples lie within the wider $\delta^{18}O_w$ frame. There is nothing exceptional about the archaeology of the outlier graves. Grave 15 is the only skeleton which is buried oriented north-south and although it contained an adult male skeleton with striking traces of ochre as well as ceramic objects, the same observations can be made for grave 9 that partly lies within the 'local' $^{87}Sr/^{86}Sr$ signature. Another (probably male) adult was buried in grave 1 but due to the poor state of preservation, no information on burial objects exists. In a region where expected $^{87}Sr/^{86}Sr$ values range between 0.709 and 0.711, the lower $^{87}Sr/^{86}Sr$ values might be the result of an influence from Mesozoic metamorphic rocks, located less than 10 km to the northeast and east, or of a mixed signal of several geological units (Fig. 4.65). As Mesozoic bedrock outcrops both nearby and much further away, the signals cannot be allocated to a distinct region. Again, the majority of $\delta^{18}O_w$ values are more depleted than the OIPC suggests. It may be that the humans in graves 2 and 9 of the Big Tumulus and grave 3 of the Tumulus in the Vineyards derive from a region with similar Sr isotopic signatures, while the humans in graves 1 and 15 of the same kurgan clearly grew up in areas of varying isotopic signatures.

Two samples were analysed from each of the skeletons in graves 1, 9 and 15 of the Big Tumulus in Ovchartsi. As expected, the two first molars from burial 1 yielded similar isotopic ratios with marginal variations due to slight differences in the time of mineralization depending on whether they were located on the mandible or the maxilla (cf. Chapter 2.2.2). The increased $\delta^{18}O_w$ values of the first molars from burials 9 and 15 might be an indicator of breastfeeding.

The 'local' $^{87}Sr/^{86}Sr$ range of Smyadovo lies between 0.7077 and 0.7087 (2σ) (Fig. 4.62). As mentioned before, the $\delta^{18}O_w$ range of all Bulgarian sites stretches from –8.55 to –6.55 ‰ or –9.15 to 5.95 ‰ (mean ± 1 ‰ or ± 1.6 ‰ respectively). Tooth enamel sampled from Smyadovo gave unexpectedly depleted $\delta^{18}O_w$ values so, rather than using the mean of all the results to estimate the 'local' $\delta^{18}O_w$ range, a mutual Bulgarian $\delta^{18}O_w$ range was substituted. Though it may be that all the humans sampled are indeed 'non-local', there are other possibilities for these values, such as the depleted $\delta^{18}O_w$ values in water sources originating in the Balkan Mountains and a higher amount of annual rainfall mixed with colder climatic conditions near the mountain range. None of the sampled humans yield isotope values that lie within both 'local' ranges. Five samples, burials 6 (M1?, M3), 13, 16 and 22 (M3), lie outside expected 'local' ranges for both oxygen and strontium. Three samples, burials 10, 15, and 26, have depleted $\delta^{18}O_w$ values, while the second tooth of burial 22 has lower than expected $^{87}Sr/^{86}Sr$ values. Burial 22 indicates that the depletion in $\delta^{18}O$ is probably not a consequence of major climatic differences between the Eneolithic and the Early Bronze Age because its first molar yields a value that is equivalent to the Early Bronze Age values from other Bulgarian sites. However, this might also arise from $\delta^{18}O$ enrichment due to a breastfeeding. In addition, the $\delta^{18}O$ value of burial 26, dating to the Early Bronze Age, is also equivalent to the Eneolithic values. The extremely low $^{87}Sr/^{86}Sr$ signature in the two teeth analysed from burial 22 hints to a place of origin, childhood and adolescence with volcanic geology. This cannot be found in the area immediately surrounding the site and makes this individual a definite

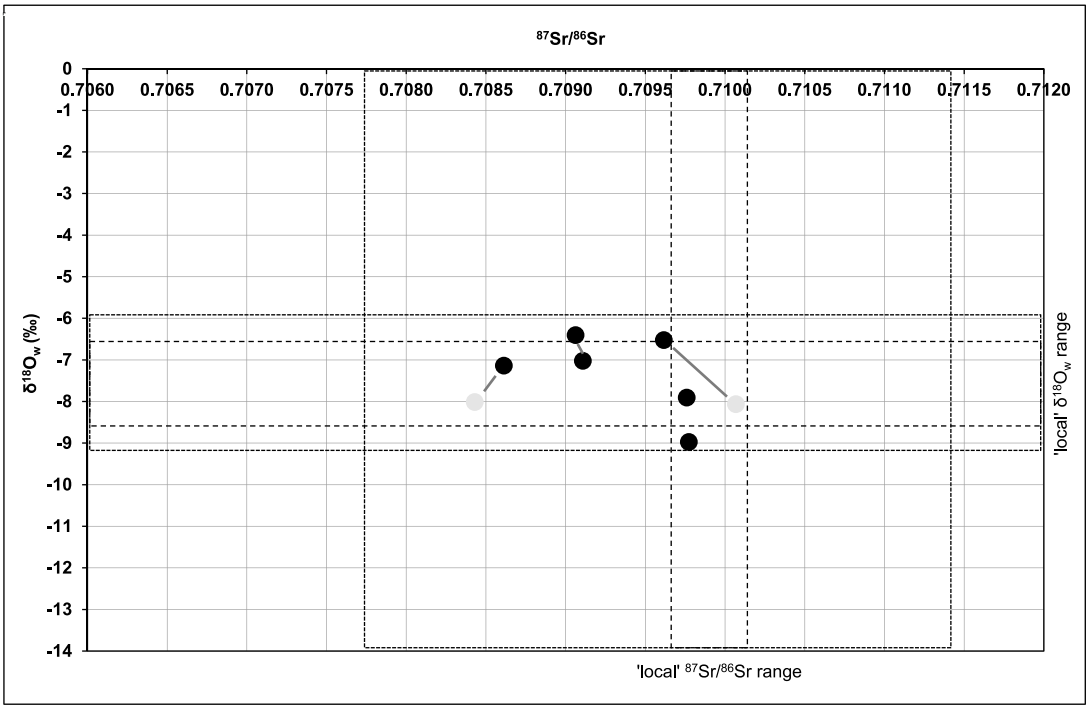


Fig. 4.61 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Ovchartsi: First molars (black circles), second molars (dark grey circles), third molars (light grey circles). Grey lines link teeth analysed from the same individual. Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

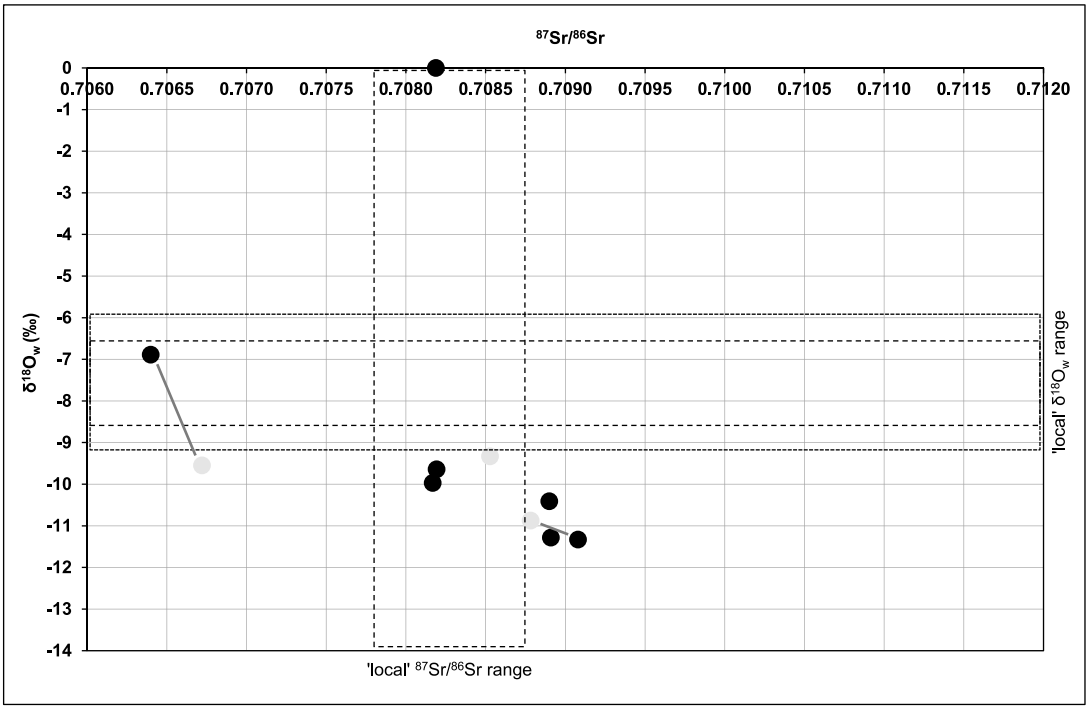


Fig. 4.62 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Smyadovo: First molars (black circles), second molars (dark grey circles), third molars (light grey circles). Grey lines link teeth analysed from the same individual. Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

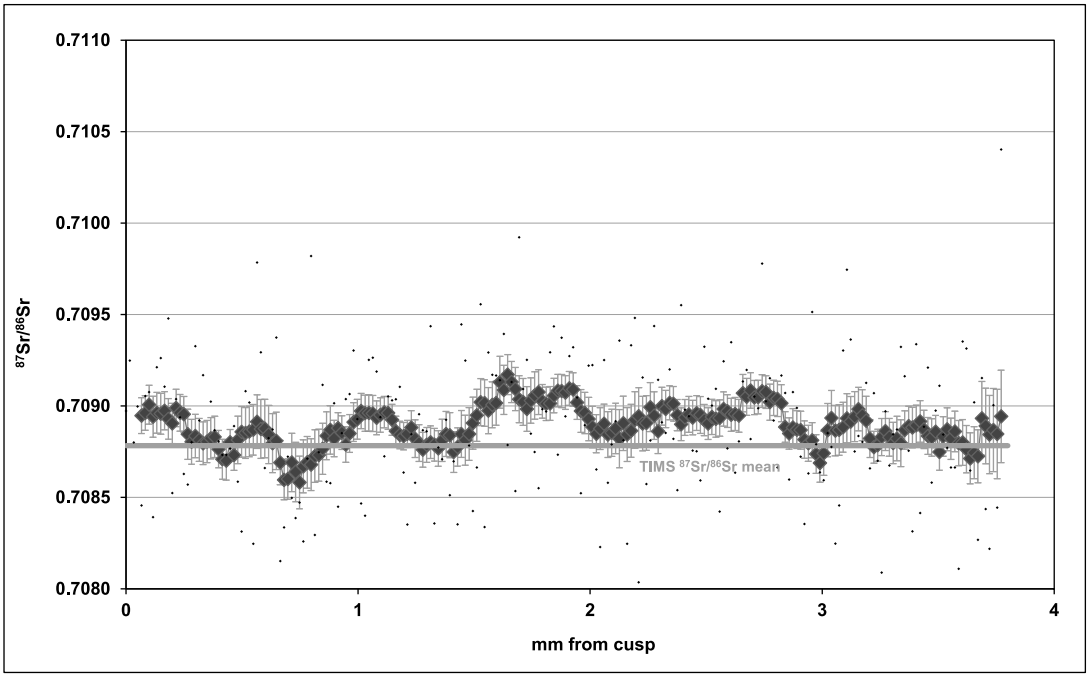


Fig. 4.63 | Data obtained by $^{87}Sr/^{86}Sr$ LA-MC-ICP-MS analysis for sample SM 12 (grave 6, male adult), including ± 1σ. The grey line shows the $^{87}Sr/^{86}Sr$ value obtained by conventional TIMS measurement of the same tooth. LA-MC-ICP-MS analysis was performed at the National Oceanography Centre facilities at the University of Southampton. For methodological details see de Jong et al., 2010; de Jong et al., in prep.

immigrant. As mentioned above, the wide difference between the first and third molar might be explained by a breastfeeding signal. Interestingly, the adolescent human died shortly after the mineralization of the third molar was completed, which raises the question of whether this person moved into the area only in the last years, or died somewhere else and was then moved to be buried at the site.

The young child in grave 15, yielding isotopic values within the $^{87}Sr/^{86}Sr$ range but below the $\delta^{18}O_w$ range, died shortly after the mineralisation of the sampled first molar was completed. This, again, either questions the reliability of the 'local' $\delta^{18}O_w$ estimate, or implies foreign origins for all individuals buried in Smyadovo. All results except the outlier agree with expected $^{87}Sr/^{86}Sr$ for Mesozoic rocks (Fig. 4.65). A possible place of origin, which is characterized by marginally elevated $^{87}Sr/^{86}Sr$ values and much depleted $\delta^{18}O_w$ ratios, would either be situated in the mountains, the Balkan Mountains being closest, or further to the northeast. According to the OIPC, $\delta^{18}O$ in modern precipitation of below –8 ‰ might be found in the Balkan Mountains, but similar isotopic ratios were seen in some of the samples from sites in southern Russia. Two small clusters of samples can be distinguished: Graves 10 and 15 with $^{87}Sr/^{86}Sr$ values about 0.7082 and graves 6, 13 and 16 with $^{87}Sr/^{86}Sr$ values around 0.709. The first two graves are similar in their east-western orientation and their burial objects, namely ceramics and ochre pieces. The second cluster of graves, all containing adult male skeletons, share east-west or southeast-northwest grave orientations.

Double isotopic analyses were performed for burial 6. While both $\delta^{18}O_w$ ratios from burial 6 were much depleted and suggest a 'non-local' infancy, both $^{87}Sr/^{86}Sr$ ratios were more enriched than expected. Intra-individual variation is relatively small, however. The third molar from this burial was

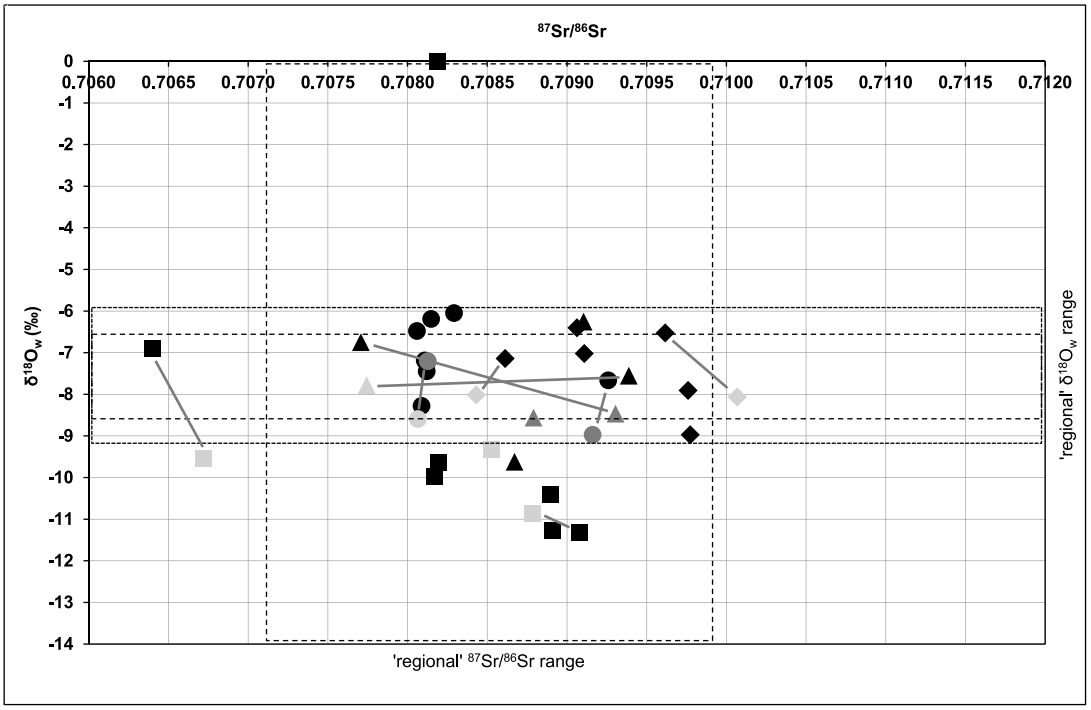


Fig. 4.64 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Benkovski (circles), Boyanovo (triangles), Ovchartsi (diamonds) and Smyadovo (squares): First molars (black circles), second molars (dark grey circles), third molars (light grey circles). Grey lines link teeth analysed from the same individual. Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

selected for additional LA-MC-ICP-MS measurements (Fig. 4.63). Only the upper tooth section could be sampled, which probably represents around two years between the age of 7 and 10 (cf. Chapter 2.2.2). It was shown that the individual consumed similar food during this time as variations in the tooth were so small. This might be associated with locally restricted mobility. The observed variations were similar to those observed for the local burials from Eulau, Germany, which were also analysed by $^{87}Sr/^{86}Sr$ LA-MC-ICP-MS (de Jong et al., 2010, fig. 2), supporting the idea that the Eneolithic individuals from Smyadovo represent a community with limited mobility or a sedentary community. The study into the dietary patterns of the individuals from Smyadovo further supports this interpretation (see Chapter 6). The Smyadovo flat cemetery is a special case since the dates of the graves are much older than the Eneolithic graves selected from further sites in this study.

The individuals sampled from Bulgaria are broadly distributed between 0.7064 and 0.7101 (2σ) for $^{87}Sr/^{86}Sr$ and between –11.33 to –6.05 ‰ in $\delta^{18}O_w$ (Fig. 4.64). The amalgamation of all values to one large 'Bulgarian' data set with combined 'regional' $^{87}Sr/^{86}Sr$ range from the summarized $^{87}Sr/^{86}Sr$ references and a supra-regional $\delta^{18}O_w$ range reveals that the majority of data points lie within these 'regional' limits; the 'Bulgarian' $^{87}Sr/^{86}Sr$ range stretches from 0.7071 to 0.7099 and encompasses all tooth enamel samples except one sample from Ovchartsi (M3 of burial 9) that is 'local' considering the $^{87}Sr/^{86}Sr$ range of the site and the two samples from grave 22 from Smyadovo which had the least radiogenic values of the complete study data set. The 'Bulgarian' oxygen range encompasses most samples except one skeleton from Boyanovo (M1 of burial 5) and all individuals despite one sample from Smyadovo. Inter-site variations can be recognised in both oxygen and strontium isotope values. There is an

increasing tendency from the least radiogenic values in Benkovski via Boyanovo and Smyadovo to the most radiogenic results in Ovchartsi. The most obvious outlier when the Bulgarian sites are considered as one group is burial 22 in Smyadovo. The majority of the results lie within the estimated $\delta^{18}O_w$ range of approximately –9 to –6 ‰ for the entire region, although all samples from Smyadovo, despite the first molar from burial 22, and the first molar from burial 5 in Boyanovo are clearly below this range. Other than that, both the expected and measured $\delta^{18}O_w$ values from the Bulgarian sites are the least depleted compared to the other regions in the study area.

Hungary

At the Eastern Hungarian site of Sárrétudvari-Őrhalom the 'local' biologically available $^{87}Sr/^{86}Sr$ ranges from 0.7101 to 0.7106 (2σ), excluding the two outlier references, and the $\delta^{18}O_w$ ranges from –9.15 to –7.15 ‰ (mean ± 1 ‰) or from –9.75 to 6.55 ‰ (mean ± 1.6 ‰) (Fig. 4.66). Four individuals have values that lie within both isotopic 'local' ranges. The Chalcolithic primary burial 12 is at the lower border of the biologically available $^{87}Sr/^{86}Sr$ range with its first molar just inside and the (probably) second premolar, which mineralizes at approximately two to seven years of age (cf. Chapter 2.2.2), slightly below that range. The isotope ratio in the second premolar of the adolescent female skeleton is similar to tooth enamel samples and reference material from other sites in the Eastern Hungarian Plain that are less radiogenic than Sárrétudvari and therefore this individual fits within the 'regional' isotopic signal range. The $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ results from graves 4, 7, 9 and 11 are more obviously outside both 'local' ranges, being 2 to 5 ‰ more depleted in $\delta^{18}O_w$ and almost 0.0005 more radiogenic in $^{87}Sr/^{86}Sr$. The results from graves 4, 7 and 9 correspond to such a degree that an isotopically similar or even corresponding region of childhood (and adolescence) can be suggested. All graves contained burials of male individuals. Graves 4 and 7/7a can be compared to each other because of their burial objects including *Lockenringe* but the three graves do not share further characteristics except for the fact that they all date to the second quarter of the 3rd millennium BC, which is more recent than the ^{14}C dates from two other graves in the burial mound. The *Lockenringe* in graves 4 and 7 are certainly indicators of a 'foreign' origin (or connection). The region(s), where these individuals lived during their childhood and/or their adolescence, is/are characterised by significantly more depleted $\delta^{18}O_w$ values and more radiogenic geology. The expected $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ ratios of the study site are between 0.709 and 0.711 and between –9 and –7 ‰. The Carpathian Mountain range is composed of a variety of different rocks of varying age resulting in $^{87}Sr/^{86}Sr$ ratios between 0.707 and 0.720 (cf. Asch, 2005). Seghedi et al. (2004, 122–126 table 1) published very low radiogenic mean values of 0.70513 ± 0.00121 for the Apuseni Mountains. Their study focused on magmatic rocks, however, and only included rocks of this type. $\delta^{18}O_w$ values would be expected to be more depleted there than in the plain of the Carpathian Basin. According to the OIPC, $\delta^{18}O$ in precipitation in the Apuseni Mountains are expected to range between –10 and –9 ‰ and can be even below –10 ‰ in the higher parts of the Carpathian Mountains. While some of the tooth enamel ratios from the North Pontic sites sampled correspond to these high $^{87}Sr/^{86}Sr$ values, $\delta^{18}O_w$ values of the outlier individuals in Sárrétudvari are even more depleted than what would be expected for the North Pontic. This suggests an origin or a childhood residence in a mountainous area rather than in the lowland plains east and southeast of the Carpathians. Nevertheless, an origin or childhood residence in the North Pontic cannot entirely be excluded. Furthermore, it should be noted that permanent stays and sequential stays in other regions, for example in association with transhumance, cannot be differentiated by analysing a longitudinal section from a tooth. The similar results from the first and third molars from grave 4 can either be interpreted as a signal for 'foreign' childhood and adolescence at iso-

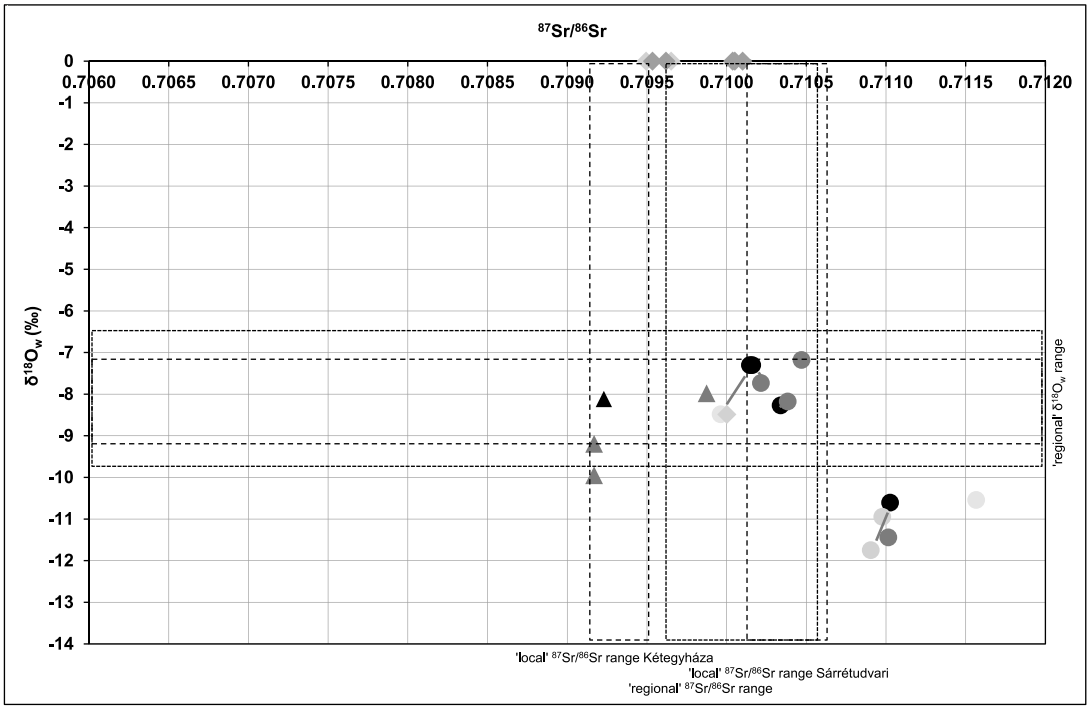


Fig. 4.66 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Sárrétudvari-Őrhalom (circles), Debrecen-Dunahalom (diamond) and Kétegyháza-Kétegyházi (triangles): First molars (black), second molars (dark grey), third molars (light grey), second premolars (very light grey). Grey lines link teeth analysed from the same individual. Estimated 'local' and 'regional' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

topically similar or corresponding regions, or as a mixed signal from several residence changes during childhood and adolescence. Grave 11 is another isotopic outlier but its $^{87}Sr/^{86}Sr$ signature is even more radiogenic than those of the preceding cluster. The grave resembles grave 9; the only burial object was a ceramic vessel and that there were animal bones on the grave filling. This skeleton shows a similar $\delta^{18}O_w$ value to the other outliers suggesting a colder and/or more elevated and/or further eastward and/or more inland place of residence while the second premolar was mineralising. Four humans from Sárrétudvari-Őrhalom were selected for duplicate $\delta^{18}O_w$ and $^{87}Sr/^{86}Sr$ analysis: the first and second molars from graves 7a and 8, the first and third molars from grave 4 and the first molar and second premolar from grave 12. There are generally only minor differences in both $\delta^{18}O_w$ and $^{87}Sr/^{86}Sr$ values intra-individually. Furthermore, there are no major variations between the teeth that mineralized at an earlier stage in life and those that mineralized at a later point suggesting no change of residence between regions of different geology or climate during childhood.

A 'local' $^{87}Sr/^{86}Sr$ range between 0.7090 and 0.7094 (2σ) and a $\delta^{18}O_w$ span of –9.15 to –7.15 ‰ or from –9.74 to 6.56 ‰ (mean ± 1 ‰ or ± 1.6 ‰) was established for Kétegyháza (Fig. 4.66). Burial 1 in kurgan 6 is the only sample that yielded a more radiogenic $^{87}Sr/^{86}Sr$ result, while burial 3 from the same kurgan was marginally more depleted in $\delta^{18}O_w$. These two burials, whilst yielding widely varying isotopic ratios, derive from the same burial mound. The primary grave in the mound, dating to the Early Bronze Age, held an adult female skeleton with no burial objects apart from one piece of ochre and ochre colouring on the bones. The isotopic result from this individual resembles grave 11 in the Sárrétudvari mound and the burial in Debrecen-Dunahalom. The skeleton in the grave in Debrecen-

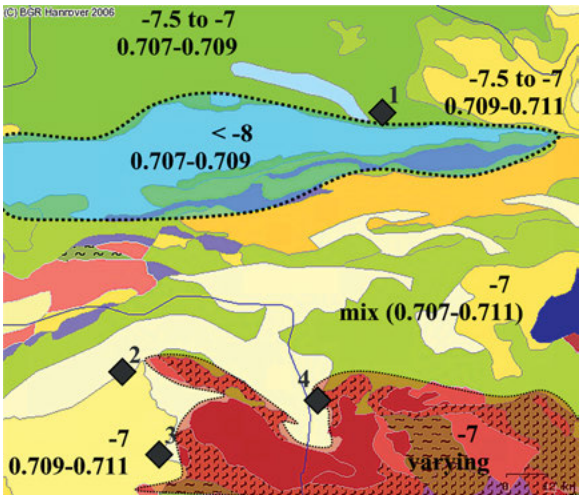


Fig. 4.65 | Geological map including estimated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (‰) ranges of the study area in Bulgaria [based on Asch, 2005 and the OIPC (Bowen, 2010)]. The locations of the sites are marked by diamonds: 1 Smyadovo, 2 Benkovski, 3 Ovchartsi, 4 Boyanovo.

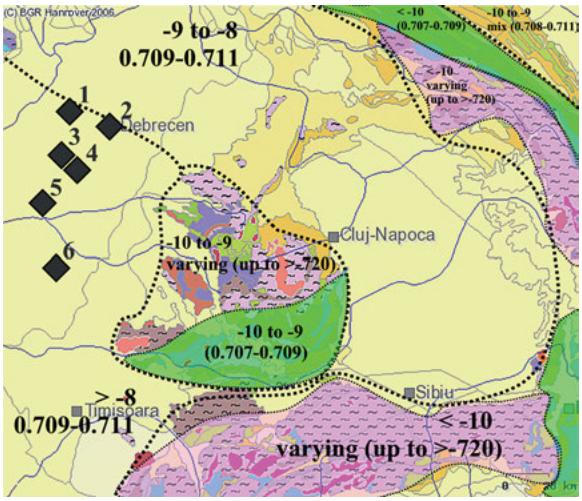


Fig. 4.67 | Geological map including estimated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (‰) ranges of the study area in Hungary [based on Asch, 2005 and the OIPC (Bowen, 2010)]. The locations of the sites are marked by diamonds: 1 Balmazújváros, 2 Debrecen, 3 Püspökladány, 4 Sárrétudvari, 5 Dévaványa, 6 Kétegyháza.

Dunahalom was also buried with red ochre spread beside the skull and legs. Grave 3 in kurgan 6 in Kétegyháza-Kétegyházi tanyák contained an adult male skeleton in a supine position with crouched legs, no burial objects but ochre colouring. The $\delta^{18}O_w$ value of the second molar of this skeleton lies between the outlier values in Sárrétudvari and the 'regional' isotopic range of the Eastern Hungarian Plain.

The Hungarian samples as a whole show a rather wide spread of tooth enamel values for both $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$, especially when the similarity in geology and climate of the Eastern Hungarian Plain are taken into consideration. The strontium ratios vary between low radiogenic values in Kétegyháza and highly radiogenic values in Sárrétudvari. The dentine reference material from other Hungarian sites lie between these two sites. The tooth enamel values from Sárrétudvari vary significantly in $\delta^{18}O_w$, yielding both the most and least depleted values. Only the skeleton in the grave in Debrecen-Dunahalom was additionally sampled for $\delta^{18}O$ analysis and the result correlates with the expected isotopic signature of the area (Fig. 4.66). A different picture emerges when all Eastern Hungarian reference values are combined in one data set. The 'regional' biologically available $^{87}Sr/^{86}Sr$ extends from 0.709 to 0.711 (2σ) and encompasses most of the tooth enamel samples. Burials 4, 7 and 9 in Sárrétudvari are at the upper border of the 'regional' $^{87}Sr/^{86}Sr$ range, while burial 11 remains a clear outlier. The very large $^{87}Sr/^{86}Sr$ range, however, is at odds with the geological homogeneity of the plain. In consequence, the four burials in Sárrétudvari are all considered outliers in respect to both strontium and oxygen isotopes.

North Pontic region

Figure 4.68 shows the estimated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ ranges of the study region in the North Pontic area. Only three samples, M1 and M2 from burial 5 and M2 from burial 20, lie within the 'local' $^{87}Sr/^{86}Sr$ range of 0.7100 to 0.7105 (2σ) at Kirovograd, whereas the wide $\delta^{18}O_w$ range from –10.9 to –7.7 ‰

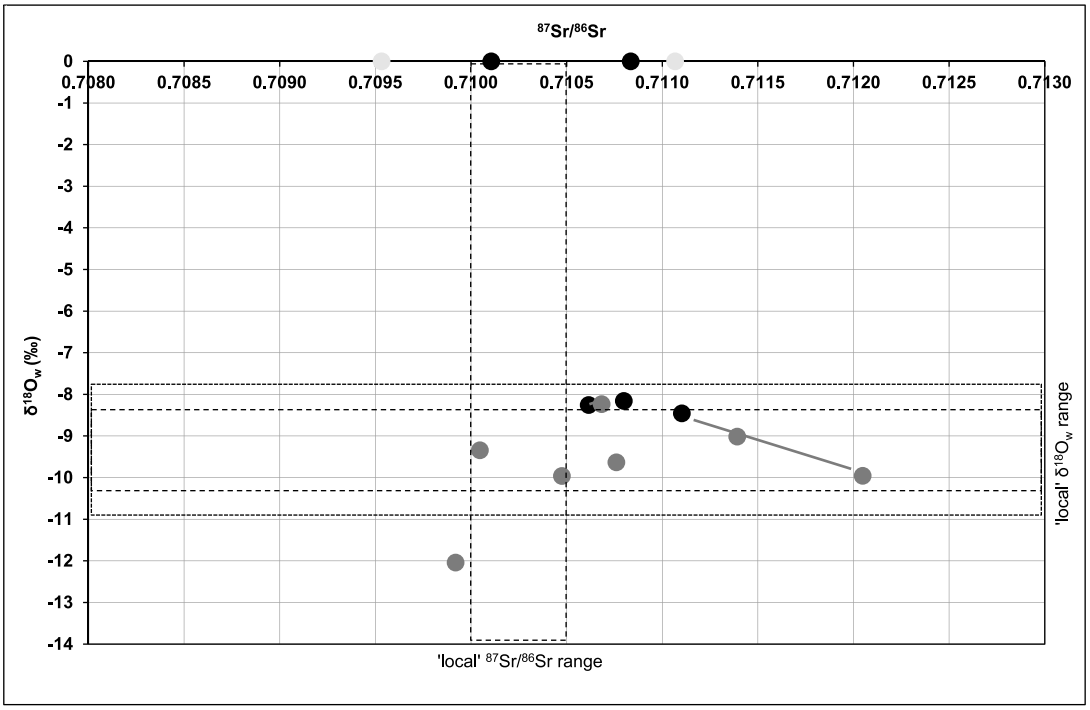


Fig. 4.68 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Kirovograd: First molars (black), second molars (dark grey), third molars (light grey). Grey lines link teeth analysed from the same individual. Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

includes all tooth enamel samples analysed except burial 16. The narrow $\delta^{18}O_w$ range from –10.3 to –8.3 ‰ additionally excludes the first and second molar from burial 13 and the first molar from burial 14. The $^{87}Sr/^{86}Sr$ outliers are graves 10 child and adult, 13, 14, 16, the second molar of grave 20 and grave 24. The wide range of $^{87}Sr/^{86}Sr$ ratios suggests residence and/or dietary shifts but this is not backed up by the narrow span of the oxygen ratios. The large variations in $^{87}Sr/^{86}Sr$ are probably the result of the pronounced geological variety in the area surrounding Kirovograd. A mixture of areas of young Cenozoic sediments with outcrops of very old rocks is found nearby and this would result in $^{87}Sr/^{86}Sr$ signature of approximately 0.709 to 0.720 (Fig. 4.74). Due to $\delta^{18}O_w$ values lie within the expected 'regional' oxygen range it is suggested that people were mobile in an area of geological diversity but climatic similarity or that they lived a more or less sedentary lifestyle with a diet deriving from varying geological regions, which can be found in a radius of less than 10 km. Since the ^{14}C dates of the graves indicate a large time span between the earliest and latest graves, the varying isotopic results could be the result of different camp sites or settlements in the closer environs of the burial mound. This does not exclude a high level of mobility between very distant regions. The only distinct isotopic outlier, mainly due to its $\delta^{18}O_w$ value, which would equal the $\delta^{18}O_w$ values obtained from the Samara region, is the Yamnaya burial in grave 16. This individual might have spent some part of their life in a region further to the east and/or to the north. The first and second molars from the child in grave 10 were sampled in duplicate and yielded varying $^{87}Sr/^{86}Sr$ ratios. Since the $\delta^{18}O_w$ values decrease in addition to the change in $^{87}Sr/^{86}Sr$ values, the suggestion that this expresses the influence of a shift from breastfeeding to solid food in earlier childhood is doubtful. It is more likely that the child moved from a region of

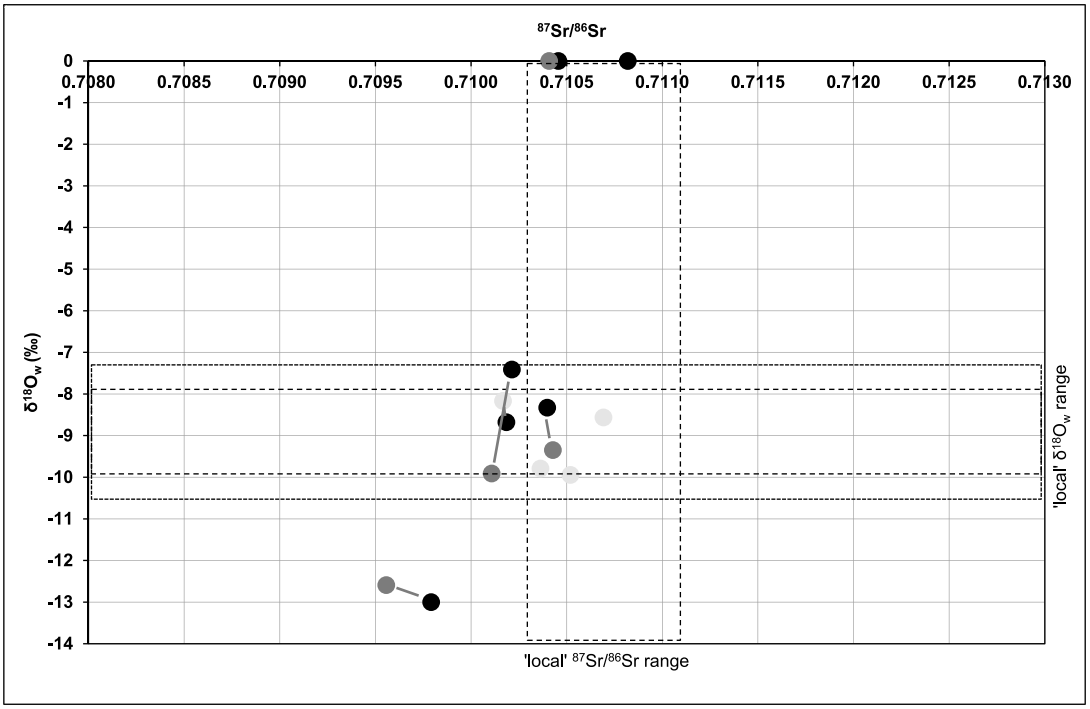


Fig. 4.69 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Peshtchanka: First molars (black), second molars (dark grey), third molars (light grey). Grey lines link teeth analysed from the same individual. Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

lower $^{87}Sr/^{86}Sr$ ratios and relatively enriched $\delta^{18}O$ to an area characterized by older sediments or rocks and of colder, more elevated and/or more inland climate with higher $^{87}Sr/^{86}Sr$ ratios and more depleted $\delta^{18}O$.

Furthermore, it is worth noting that the only two burials containing wagon (parts), burials 5 and 20, have isotope values that lie at least partly within the 'local' isotopic ranges. The higher degree of human mobility suggested for individuals in wagon burials is not evident in the isotopic signal which, it must be remembered, only reflects the early years of life.

In Peshtchanka, results of four samples from two skeletons, burials 10 and 12, lie within the wider limits of the 'local' $^{87}Sr/^{86}Sr$ range (Fig. 4.69). Four samples from three skeletons, burials 6, 12 and 15, lie outside the 'local' strontium and oxygen ranges. The 'local' strontium signature ranges from 0.7103 to 0.7111 (2σ), excluding the outlier references, and the 'local' $\delta^{18}O_w$ ranges from –9.9 to –7.9 ‰ or –10.5 to –7.3 ‰ (mean ± 1 ‰ and ± 1.6 ‰ respectively). The first and second molars from burial 14, which is one of the four Eneolithic burials, are distinct isotopic outliers. There are no archaeological or anthropological differences between burial 14 and the other graves apart from the supine position of the skeleton, which corresponds with the characteristics of the local Kvityana culture (see Chapter 2.1.2), while the crouched burial position of the human in grave 15 corresponds to the Lower Mikhailovka burial tradition. The $\delta^{18}O_w$ values of this outlier individual were similar to those from humans sampled in the Middle Volga region. The $^{87}Sr/^{86}Sr$ value is rather unspecific and could be the result of Cenozoic sediments or a mixed signal from Mesozoic and Cenozoic geology. A place of origin further to the north, the northeast or the east would therefore be suggested, such as the Don region, where the Repin culture is

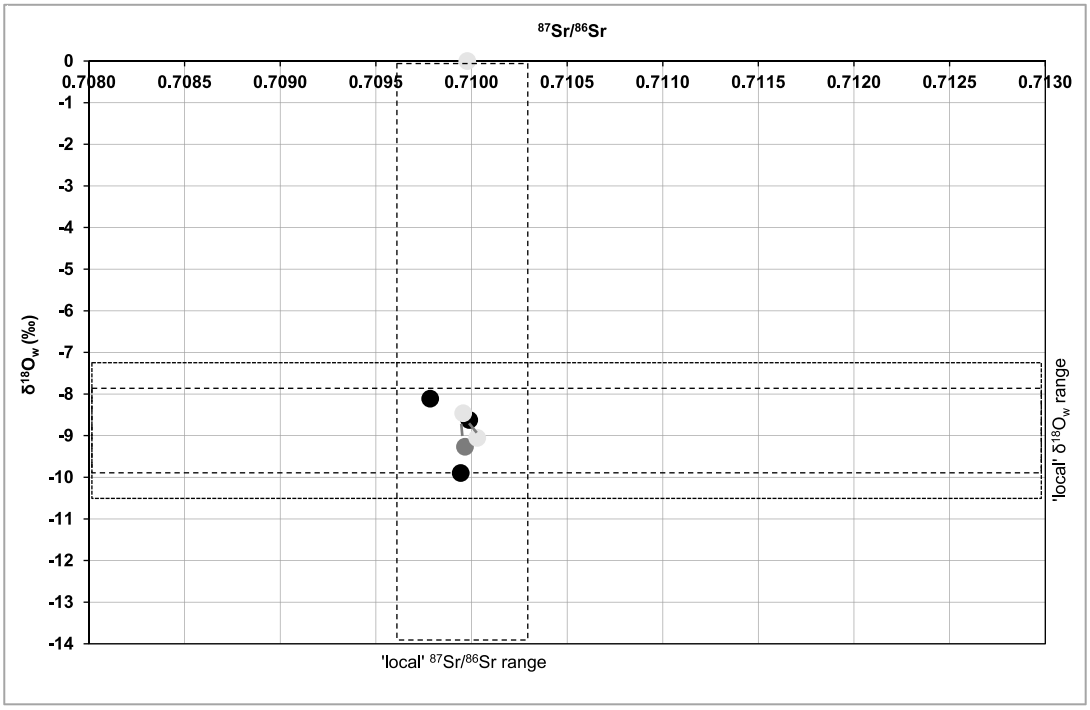


Fig. 4.70 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Shakhta Stepnaya: First molars (black), second molars (dark grey), third molars (light grey). Grey lines link teeth analysed from the same individual. Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

contemporaneously distributed. However, it would be expected that the oxygen isotope ratios there would be less depleted. Considering $\delta^{18}O_w$ values of the other Eneolithic individuals from the same site a chronological shift in $\delta^{18}O$ caused by climatic differences seems unlikely. The skeletons in the Yamnaya grave 10 and the Catacomb grave 12 yielded very similar results outside the smaller 'local' $^{87}Sr/^{86}Sr$ range, but first and second molars from burial 12 differ significantly in respect to $\delta^{18}O$. This might be due to a breastfeeding effect in the first molar. These graves and grave 7 are the only burials containing grave goods.

Figure 4.70 shows the distribution of all sampled tooth enamel values from Shakhta Stepnaya. The more limited $^{87}Sr/^{86}Sr$ range from 0.7096 to 0.7103 (2σ) includes all tooht enamel samples. Two tooth enamel samples, burial 7 in kurgan 2 and burial 10 in kurgan 4, are at the border to the wider $\delta^{18}O_w$ range of below –9.9 and above –7.9 ‰. The first molar from the adult skeleton in grave 10 in kurgan 4 is marginally enriched in $\delta^{18}O_w$. This burial of a young female skeleton and a child can be dated to the Developed Catacomb culture and is the only sampled burial with a larger range of grave goods. The sketelon in grave 11 of kurgan 4 in Shakhta Stepnaya was sampled in duplicate. It yielded similar $^{87}Sr/^{86}Sr$ ratios from the second and third molars. The $\delta^{18}O_w$ ratios showed a slightly increasing trend, but the difference is too small to suggest a change of residence. There was probably no change of either the geological or the climatic region between childhood and adolescence.

The biologically available $^{87}Sr/^{86}Sr$ in Vinogradnoe, excluding the obvious outlier reference material, ranges from 0.7095 to 0.7103 (2σ). The 'regional' $\delta^{18}O_w$ signature is estimated to range between –9.9 and –7.9 ‰ (and –10.5 to 7.3 ‰), which is based on a 1 ‰ (and 1.6 ‰) deviation around

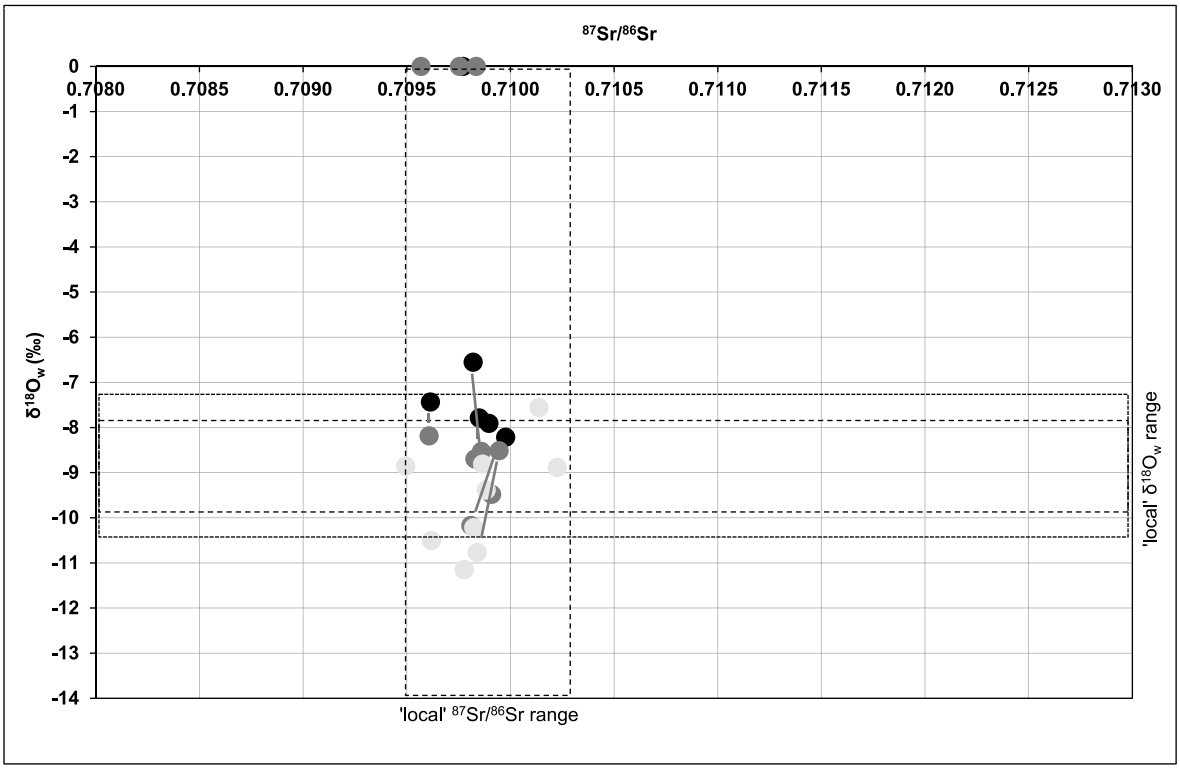


Fig. 4.71 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Vinogradnoe: First molars (black), second molars (dark grey), third molars (light grey). Grey lines link teeth analysed from the same individual. Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

the $\delta^{18}O_w$ mean of –8.9 ‰. All sampled teeth lie within the range of the 'local' biologically available $^{87}Sr/^{86}Sr$, whereas one sample (kurgan 24 grave 15 skeleton 2) plots at the lower border of the range (Fig. 4.71). Nine teeth yielded values lying outside the narrow $\delta^{18}O_w$ range. Only four teeth, burial 25 in kurgan 3, skeleton 2 in burial 8, skeleton 1 in burial 15 and burial 22 in kurgan 24, fell outside the wider $\delta^{18}O_w$ range. The result of the third molar from skeleton 2 in grave 15, kurgan 24 lay at the limit of the narrow $^{87}Sr/^{86}Sr$ range, while the second individual from the same grave, an Early Catacomb double burial of a female and a male, was an outlier in terms of $\delta^{18}O_w$. The one skeleton, yielding a more enriched $\delta^{18}O_w$ result than that estimated for the 'local' range, burial 22 in kurgan 24, was buried together with several metal objects, other grave goods as well as ochre, objects of organic material and a wooden grave cover. The third molar, in contrast to the first one, yielded a 'local' result, indicating that the enrichment might be the result of a breastfeeding signal or a residence change to another climate during infancy. Five burials, grave 15 skeleton 1 and grave 26 in kurgan 24 and grave 25 in kurgan 3, yielded $\delta^{18}O_w$ values below the wide 'local' $\delta^{18}O_w$ range. The latter grave contained four wooden wheels and bone and bronze objects, which defines it as a well equipped Yamnaya grave. Two wooden objects were placed in grave 26 in kurgan 24, a burial of the Developed Catacomb culture. Skeletons 1 and 2 in grave 34 in kurgan 24, dating to the Early Catacomb culture and containing wooden wheels, yielded $\delta^{18}O_w$ values below the narrow 'local' range. These results suggest that the individuals in the sampled graves with wheels had an origin to the east, the northeast or north of the burial site. There is an area of Proterozoic bedrock east of Vinogradnoe, which is characterized by more radiogenic strontium ratios.

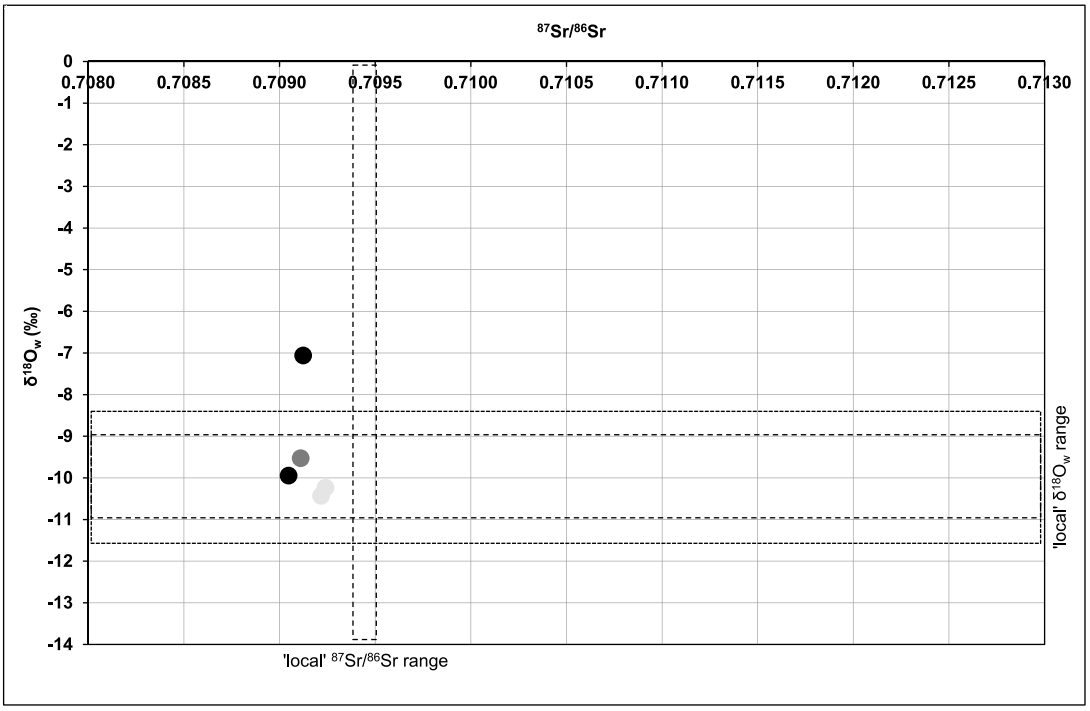


Fig. 4.72 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Nevskoe: First molars (black), second molars (dark grey), third molars (light grey). Grey lines link teeth analysed from the same individual. Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

The strontium ratios of the skeletons in the graves with wheels, however, do not differ from the remaining graves so this would seem to discount the likelihood that the area of origin lies to the east. Disregarding the rather small variations in $\delta^{18}O_w$, the origin of the outlier individuals might therefore be north of the burial site, where the geology is generally identical. Minor differences are probably the result of mixed signals. Important to note is the distribution of the $\delta^{18}O_w$ values of first, second and third molars at the site. While first molars tend to be enriched in $\delta^{18}O$, third molars tend to show more depleted values. Second molars lie in between the two. This might be a good example for $\delta^{18}O$ enrichment in teeth that mineralize during breastfeeding.

At Nevskoe, the 'local' $^{87}Sr/^{86}Sr$ signature was derived from three dentine reference samples and gave a very narrow range of 0.7094 to 0.7095 (2σ) (Fig. 4.72). The questionable nature of this 'local' $^{87}Sr/^{86}Sr$ signature makes it impossible to define the samples from Nevskoe as 'local' or 'non-local' based purely on their strontium results. The mixed geology of Cenozoic and Mesozoic suggests values to range between 0.707 and 0.711 (Fig. 4.74). The 'local' $\delta^{18}O_w$ range, between –11 and –9 ‰ accounting for a 1 ‰ standard deviation, encompasses four of the five sampled individuals. The isotopic similarity of these four individuals suggests similar or even identical movement patterns that differ only slightly in isotope ratios to the burial environment. The one outlier individual, grave 9 in kurgan 5, yielded a significantly less depleted $\delta^{18}O_w$ value, in fact one of the most enriched oxygen isotope ratios of the North Pontic samples. Since the first molar of this skeleton was sampled, the possibility that the enrichment in $\delta^{18}O$ might be caused by breastfeeding cannot be discounted. The $^{87}Sr/^{86}Sr$ result indicates a mixed signal from Cenozoic and Mesozoic bedrock but would also match the characteristic $^{87}Sr/^{86}Sr$ range for the

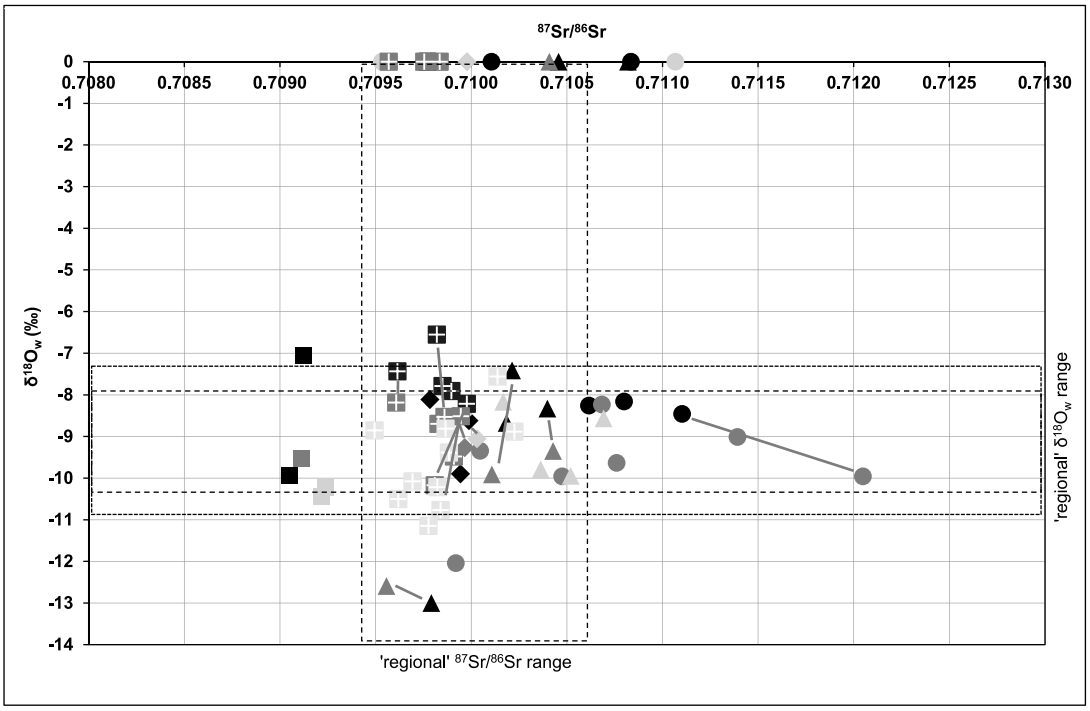


Fig. 4.73 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Kirovograd (circles), Nevskoe (squares), Peshtchanka (triangles), Shakhta Stepnaya (diamonds), Vinogradnoe (crossed squares): First molars (black), second molars (dark grey), third molars (light grey). Grey lines link teeth analysed from the same individual. Estimated 'regional' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

Central Ukrainian steppe zone, although it would correspond to the lower end of that range. From an archaeological point of view the skeleton does not differ significantly from the other skeletons sampled. It is a single burial of a juvenile individual and contained a range of burial objects including ceramic and wooden vessels, ochre foot-prints and a grave cover. Ochre prints are one of the characteristics of the Ingul culture, which is distributed west of the Dnieper. Both archaeological evidence and isotopic analyses suggest some kind of relation between this individual and the distribution area of the Ingul variant further southwest.

The amalgamation of all references from the five North Pontic sites gives a surprisingly uniform pattern, resulting in a narrow 'regional' $^{87}Sr/^{86}Sr$ range of 0.7094 to 0.7108 (2σ) and an estimated 'regional' $\delta^{18}O_w$ range between –10.3 and –7.9 ‰ or –10.9 and –7.3 ‰ (mean ± 1 ‰ or 1.6 ‰ respectively) (Fig. 4.73). The tooth enamel samples from the North Pontic yield widely distributed $^{87}Sr/^{86}Sr$ values. On a regional scale the results from Nevskoe are clustered tightly with the lowest radiogenic signals, whereas the skeletons from Kirovograd are diverse and yield the highest radiogenic signals. The $^{87}Sr/^{86}Sr$ results from Vinogradnoe, Shakhta Stepnaya and Peshtchanka are arranged between these two extremes, with very restricted ranges in Vinogradnoe and Shakhta Stepnaya. These two sites, conversely, yield the most diverse $\delta^{18}O_w$ ranges. Despite the geological and climatic similarity of the North Pontic region, there is a clear trend to a lower radiogenic $^{87}Sr/^{86}Sr$ signature in the east and a higher signal in the west of the area (Fig. 4.74). There is no obvious trend in $\delta^{18}O_w$ values though. The five less radiogenic samples from Nevskoe and the four teeth which are more radiogenic from Kirovograd (burial 10 child and adult) and the one tooth from Peshtchanka (burial 6) are outliers with respect to $^{87}Sr/^{86}Sr$. Apart

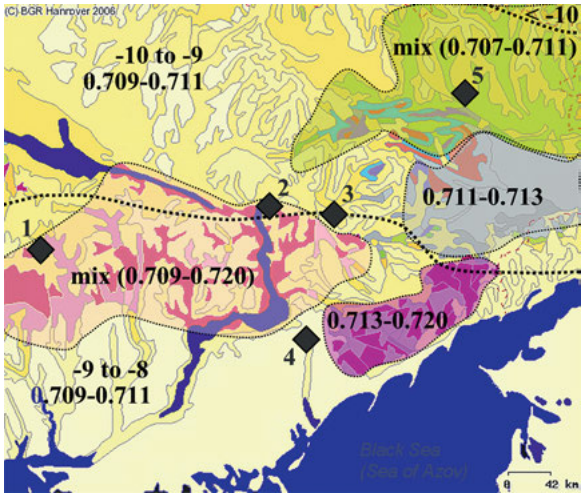


Fig. 4.74 | Geological map including estimated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (in ‰) ranges of the study area in the North Pontic region [based on Asch, 2005 and the OIPC (Bowen, 2010)]:
The locations of the sites are marked by diamonds: 1 Kalinovka, 2 Peshtchanka, 3 Shakhta Stepnaya, 4 Vinogradnoe, 5 Nevskoe.

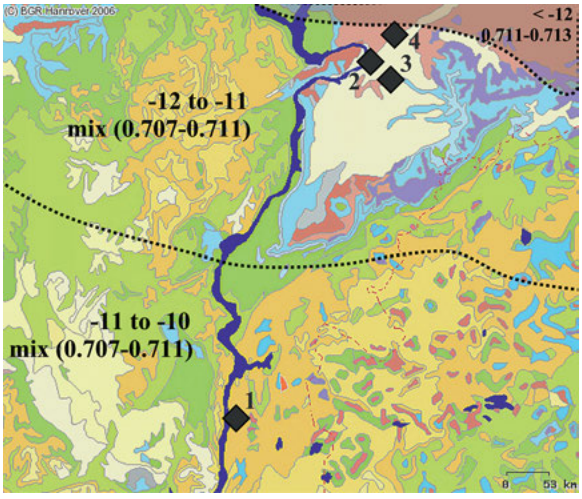


Fig. 4.81 | Geological map including estimated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (‰) ranges of the study area in the middle Volga region [based on Asch, 2005 and the OIPC (Bowen, 2010)]. The locations of the sites are marked by diamonds: 1 Politotdel'skoe, 2 Nikolaevka, 3 Podlesnyi, 4 Kalinovka.

from one skeleton from Nevskoe, all these outliers fall within the scope of the estimated $\delta^{18}O_w$ range for the entire North Pontic sample region. However, some of the individuals that yield 'local' $^{87}Sr/^{86}Sr$ results have $\delta^{18}O_w$ values that lie below the wider 'regional' range. These are one individual from each Kirovograd (burial 16) and Peshtchanka (burial 14) and, to a minor degree, one skeleton from Vinogradnoe (skeleton 1 grave 15 kurgan 24). Two samples including three teeth from Vinogradnoe (burial 22 in kurgan 24), and one tooth from Nevskoe (burial 9 in kurgan 5), lie above the wide 'regional' $\delta^{18}O_w$ range.

Volga region

The 'local' biologically available $^{87}Sr/^{86}Sr$ at Kalinovka I, estimated by selecting two dentine and two animal bone samples, results in a range between 0.7089 and 0.7094 (2σ), and the 'regional' $\delta^{18}O_w$ range for the Samara region lies between –12.15 and –10.15 ‰ or –12.75 and –9.55 ‰ (to 1 ‰ or 1.6 ‰ SD respectively). Two of the tooth enamel values, burials 3 and 6 in kurgan 1, are less radiogenic than the 'local' $^{87}Sr/^{86}Sr$ range but lie within the estimated 'regional' $\delta^{18}O_w$ range, at least the wider range (Fig. 4.75). Archaeologically, burials 3 and 6 differ from grave 4 in the east–western orientation of their burial pits and the evidence of organic materials and further grave goods, though all of the sampled graves from the Middle Volga region belong to the Poltavka culture and all contained burials of older individuals. The $^{87}Sr/^{86}Sr$ values were lower than the 'local' range and might reflect a signal from the Mesozoic bedrock in the more distant area west of the River Volga (Fig. 4.81), or corresponding to the distribution of the Poltavka culture to the south, but due to the minor nature of the variations, this remains uncertain.

The very narrow 'local' $^{87}Sr/^{86}Sr$ range of 0.7094 to 0.7098 (2σ) of Nikolaevka III, defined by four dentine samples, is more radiogenic than all the tooth enamel samples from the site (Fig. 4.76). Only one human individual, skeleton 1 in grave 1 of kurgan 3, yields results that also lie outside the limits of the narrow $\delta^{18}O_w$ range. All sampled skeletons show similarities in their burial tradition, apart from

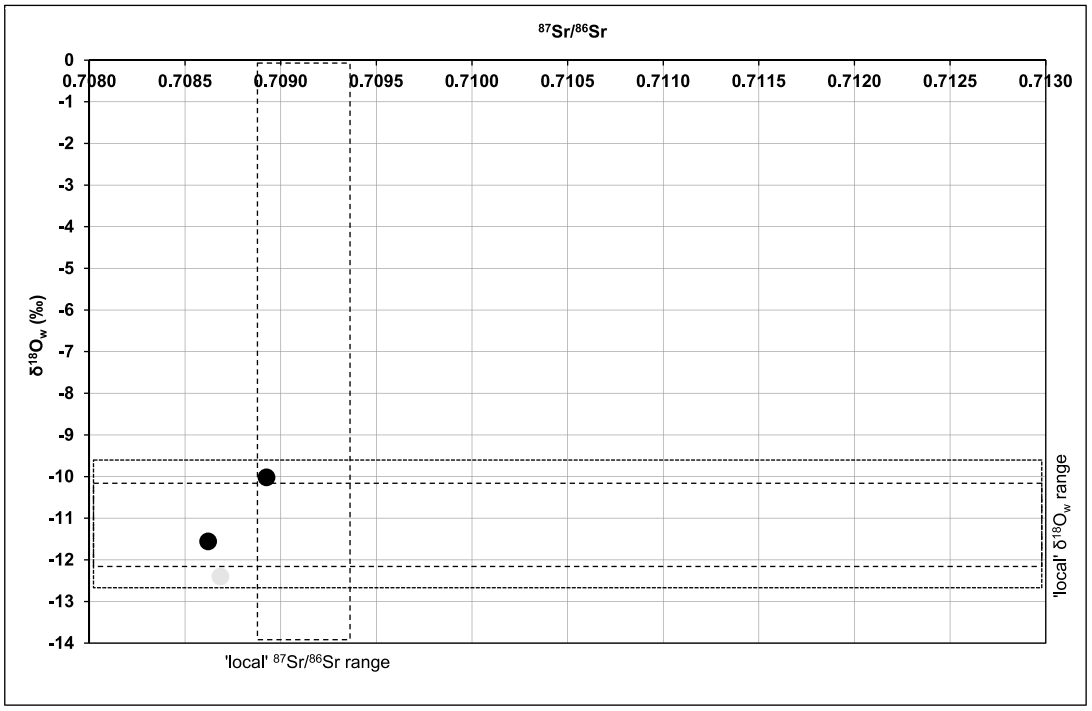


Fig. 4.75 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Kalinovka I: First molars (black), second molars (dark grey), third molars (light grey). Grey lines link teeth analysed from the same individual. Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

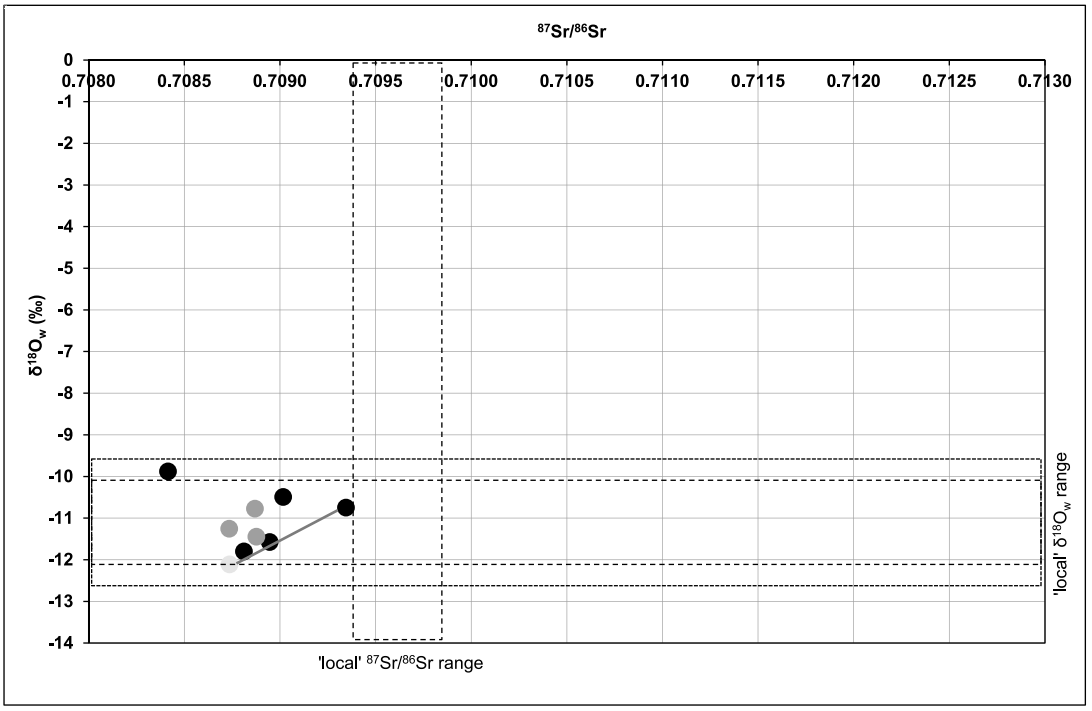


Fig. 4.76 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Nikolaevka III: First molars (black), second molars (dark grey), third molars (light grey). Grey lines link teeth analysed from the same individual. Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

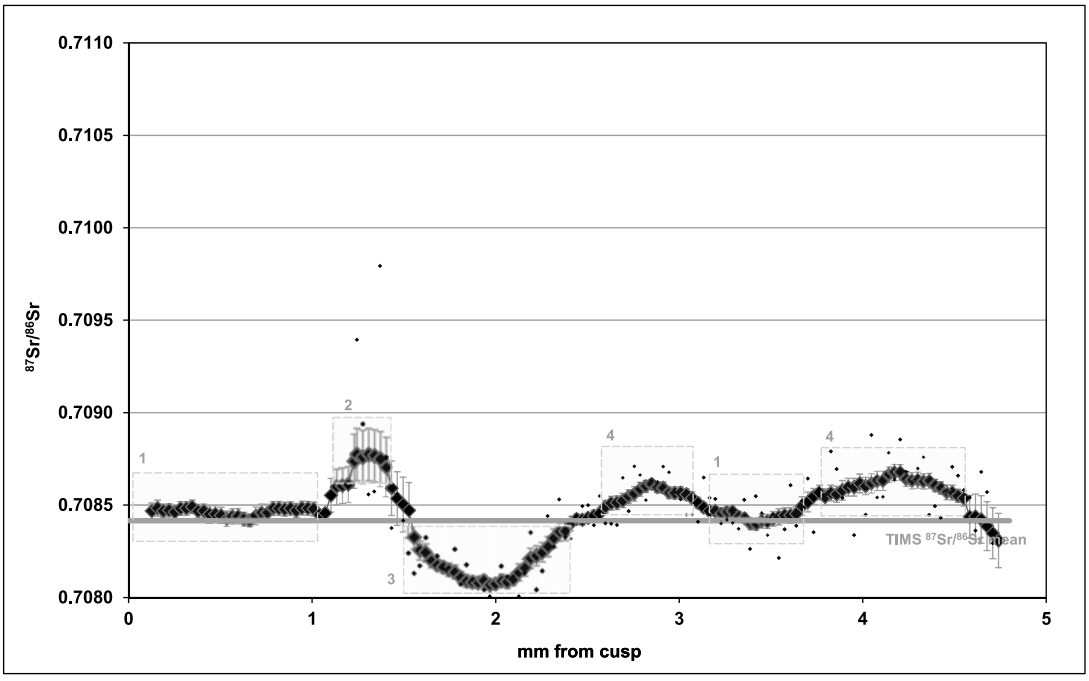


Fig. 4.77 | Data obtained by $^{87}Sr/^{86}Sr$ LA-MC-ICP-MS analysis for sample Wo 8 (kurgan 3 grave 1 individual 1, *Infans* II, male?, M1), including ± 1σ. The grey line shows the $^{87}Sr/^{86}Sr$ value obtained by conventional TIMS measurement of the same tooth. Grey frames indicate potential places of residence.
LA-MC-ICP-MS analysis was performed at the National Oceanography Centre facilities at the University of Southampton. For methodological details see de Jong et al., 2010; de Jong et al., in prep.

the first molar from the child in double burial 1 in kurgan 3, which was buried with more burial objects than the other skeletons. This human yields results most at variance from the 'local' signature, with an isotopic signal more characteristic of Mesozoic geology or a mixture between Mesozoic and the 'local' geology. Mesozoic geology occurs less than 50 km to the southeast (Fig. 4.81). In consequence, this skeleton is isotopically (and archaeologically) significantly different from the remaining skeletons in Nikolaevka III. The isotopic similarity of the all individuals except this outlier suggests a common place or region of residence. Since the different teeth of various human individuals represent varying time periods it might even be suggested that these individuals were not very mobile. The first molar from individual 1 in kurgan 3 grave 1 was additionally obtained for $^{87}Sr/^{86}Sr$ LA-MC-ICP-MS measurements (Fig. 4.77). The first molar starts mineralizing *in utero* and therefore partly reflects the $^{87}Sr/^{86}Sr$ signal of the mother rather than the infant (cf. Chapter 2.2.2). Furthermore, variations are small (places 1 and 4?) and might be related to birth and breastfeeding (places 2 and 3?). Nevertheless, it can be argued that the wave-like pattern reflects seasonal mobility within a geologically similar region. Duplicate analysis was performed for skeleton 2 in kurgan 2 grave 1. There is a decrease in both $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ between the first and the third molar, which could be due to a weaning signal or a change of residence to a region with less radiogenic geology and more depleted $\delta^{18}O$ ratios.

The 'local' $^{87}Sr/^{86}Sr$ range from 0.7088 to 0.7095 (2σ) in Podlesnyi was established from three dentine samples and it does not encompass any of the rather scattered tooth enamel values (Figure 4.78). The third molar from burial 6 and the first molar from burial 3 in kurgan 3 yield results that lie outside both strontium and oxygen 'local' isotopic ranges. There are no distinct differences in the burial rite,

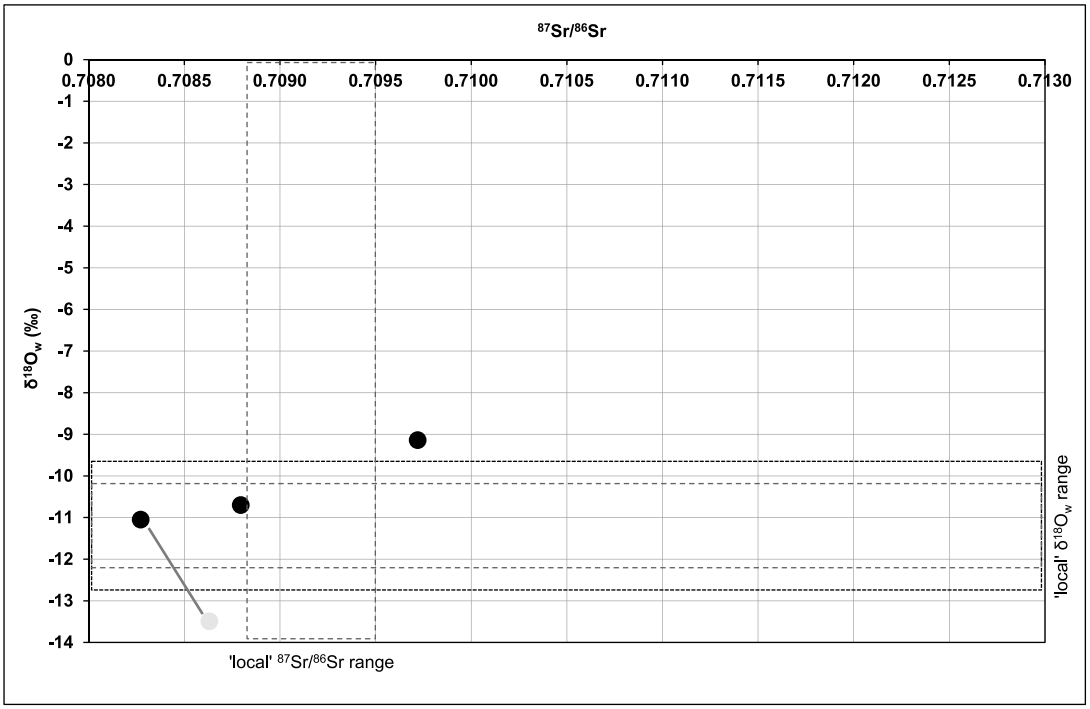


Fig. 4.78 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Podlesnyi: First molars (black), second molars (dark grey), third molars (light grey). Grey lines link teeth analysed from the same individual. Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

because all individuals are associated with the Poltavka culture. This culture is distributed along the Lower and Middle Volga, so the human in kurgan 3 grave 3 might come from a place further south, while the human in kurgan 3 grave 6 might have moved further north or east in their adolescence. An increase in both $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ has been observed between the first and third molar of this individual, which might be the result of a change of residence or of a weaning signal. However, the $^{87}Sr/^{86}Sr$ value does not correspond to the geology immediately north of Podlesnyi. The location of the site in a region of mixed geological bedrock leads to the suggestion that the results reflect the large geological variations of the area (Fig. 4.81). Combined with the scattered $\delta^{18}O_w$ values, it may be suggested that these people had a higher degree of mobility or represent different communities.

At Politotdel'skoe the 'local' $^{87}Sr/^{86}Sr$ range estimated by two dentine samples is not very reliable (Fig. 4.79). Due to this and to similar $^{87}Sr/^{86}Sr$ values, it remains unclear whether all individuals should be considered as 'locals' or 'non-locals' in respect to strontium. The location of the site suggests a mixed signal from Mesozoic and Cenozoic geology, which is well reflected by the results (Fig. 4.81). Nevertheless, due to the geological homogeneity of the wider area, wide-ranging mobility would not be shown by the $^{87}Sr/^{86}Sr$ ratios. All tooth enamel values fall within the scope of the 'local' $\delta^{18}O_w$ range of –10.6 to –8.6 ‰ so it is suggested to consider all three human individuals to be 'locals'.

All results of the $^{87}Sr/^{86}Sr$ analysis from the Middle Volga region lie within a limited range of 0.7083 to 0.7097 (2σ) (Fig. 4.80). The human individuals from Podlesnyi yielded both the lowest and the highest $^{87}Sr/^{86}Sr$ ratios. Figure 4.81 shows that a mixed signal deriving from Cenozoic and Mesozoic geology in varying degrees can be expected for all sites. The amalgamation of all the references from the four sample sites in the vicinity of the river Volga to establish a 'regional' $^{87}Sr/^{86}Sr$ signature is problem-

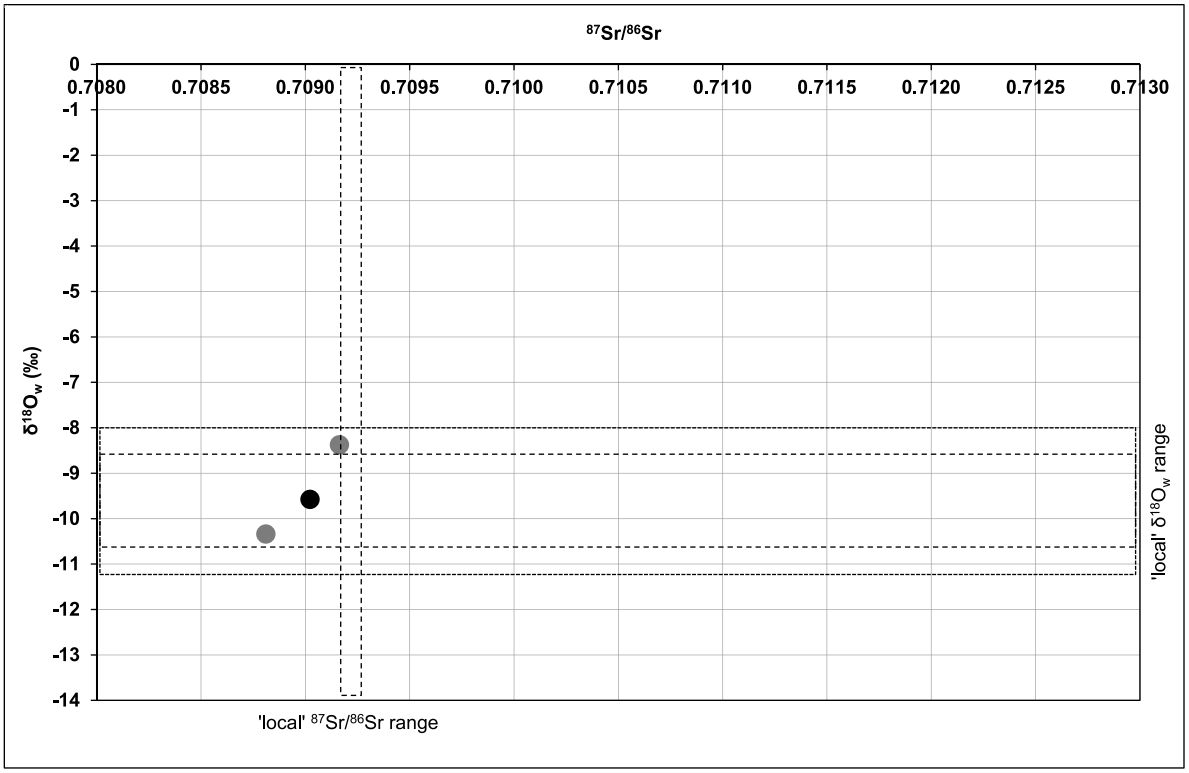


Fig. 4.79 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Politotdel'skoe: First molars (black), second molars (dark grey), third molars (light grey). Grey lines link teeth analysed from the same individual. Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

atic, because the underlying geology differs significantly between the sites. Although the range of biologically available 'regional' $^{87}Sr/^{86}Sr$ seems fairly closely defined between 0.7088 and 0.7098 (2σ), this is caused by the exclusive use of dentine and bone as references, and half of the enamel sample results are less radiogenic than this 'local' $^{87}Sr/^{86}Sr$ range. The results from oxygen isotope analysis yield a wider range. This range might be explained by the fact that Politotdel'skoe is situated several hundred kilometres to the south of the Samara region and would therefore be expected to have less depleted $\delta^{18}O_w$ ratios (–11 to –10 ‰) than the other sites (–12 to –11 ‰). Most tooth enamel samples are consistent with the estimated 'regional' $\delta^{18}O_w$ range of –12.15 to –8.6 ‰. However, burial 3 in kurgan 3 in Politotdel'skoe yielded a less depleted value, while the third molar from burial 6 in kurgan 6 in Podlesnyi is the only sample that lies significantly outside both isotopic 'regional' ranges, whereas the sample from burial 6 in kurgan 1 in Kalinovka I is only marginally outside the 'regional' ranges.

South Russia

The geology in the region around Sukhaya Termista II and Olennii consists of Cenozoic sediments, and does not differ significantly. Thus $^{87}Sr/^{86}Sr$ values between 0.709 and 0.711 are expected for both sites. Nonetheless, there is a slight difference in the results from the sites with consistently less radiogenic values from Sukhaya Termista II. Despite the sites not being close, which is why differences in $\delta^{18}O$ values are to be expected, all tooth enamel samples yielded rather similar $\delta^{18}O$ results.

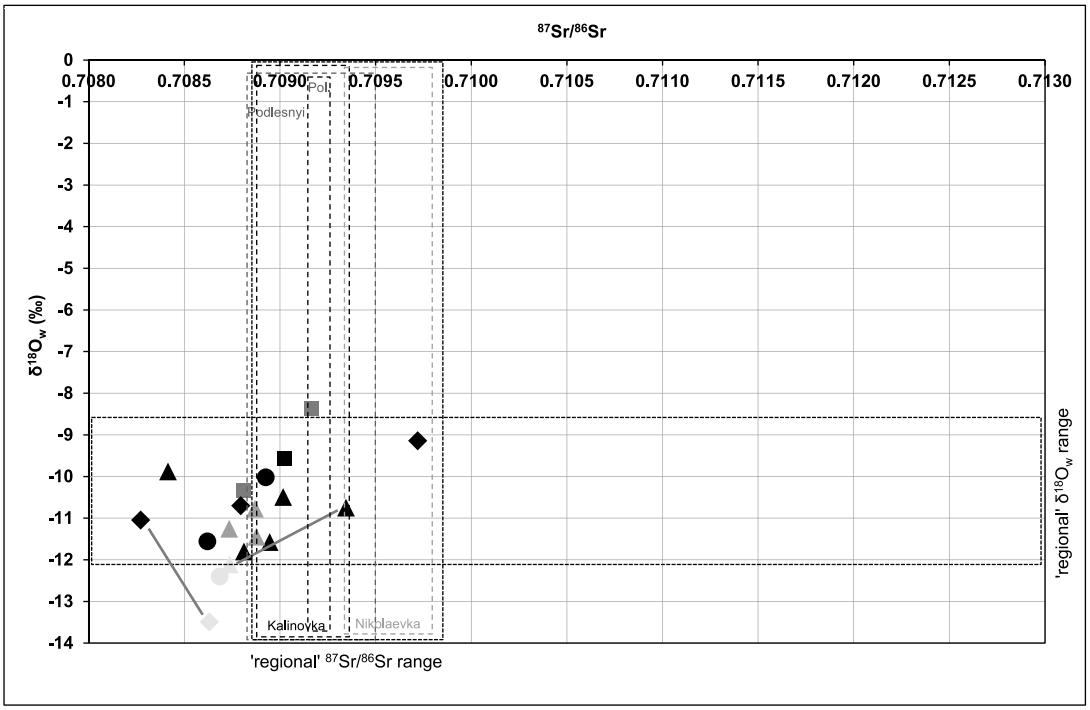


Fig. 4.80 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Kalinovka (circles), Nikolaevka (triangles), Podlesnyi (diamonds) and Politotdel'skoe (squares): First molars (black), second molars (dark grey), third molars (light grey). Grey lines link teeth analysed from the same individual. Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

The limited 'local' $^{87}Sr/^{86}Sr$ range of 0.7094 to 0.7095 (2σ) at Olennii was calculated from three dentine samples and does not encompass all the tooth enamel results, although they are also very constrained (Fig. 4.82). According to the OIPC, $\delta^{18}O_w$ values around –9 to –8 ‰ are expected for the region of Olennii (Fig. 4.84). All $\delta^{18}O_w$ results apart from grave 21b in kurgan 1 lie within the narrow 'local' $\delta^{18}O_w$ range of –9.6 to –7.6 ‰, and even this is only slightly below the 'local' range and is therefore not considered an outlier.

In respect to $^{87}Sr/^{86}Sr$ only human 2 in grave 25 in kurgan 2 counts as an outlier because the dentine sample from this skeleton yielded an equivalent $^{87}Sr/^{86}Sr$ value to the remaining dentine and tooth enamel results. The skeleton in question is placed in a supine position with flexed legs. A typical Novotitarovskaya culture burial features the skeleton crouched on the side, which is the case for the other skeletons sampled. The skeleton in question is an *Infans* I with burial objects that showed connections with the Caucasus Mountains (pers. comm. A. Gei) and a wagon, which was deposited next to the burial pit. All the burials belong to the Novotitarovskaya culture, for which the deposition of wagons and wagon parts is a common feature (see Chapter 2.1.3.5), but this is the only grave sampled containing a wagon. In consequence, a 'non-local' $^{87}Sr/^{86}Sr$ value and partly uncommon features of the burial objects are opposed to a 'local' $\delta^{18}O_w$ value and the addition of a wagon and complicate the interpretation of the data. Due to the fact that deciduous teeth mineralize *in utero* and reflect the isotopic signature of the mother at the time of pregnancy, the evidence might point to a 'non-local' origin of the child's mother, expressed in a mixture of different burial traditions.

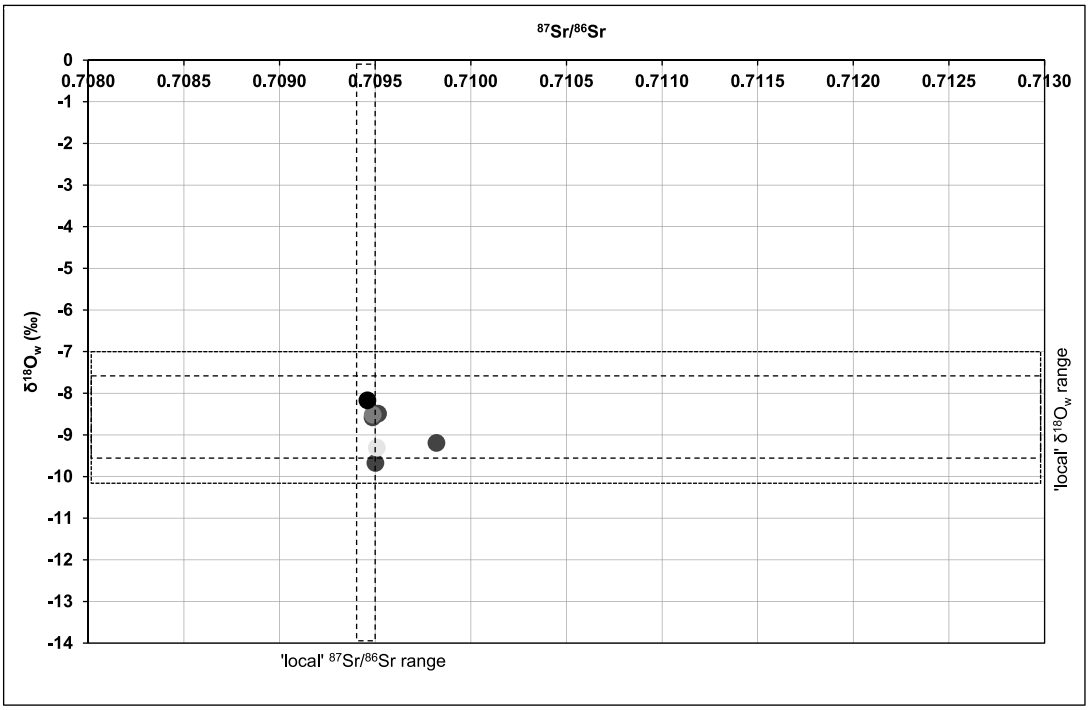


Fig. 4.82 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel Olennii: Canines (light black), deciduous second molars (dark grey), second molars (medium grey), third molars (light grey). Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

The sampling of deciduous teeth from skeleton 2 in grave 25, the two children in grave 35 in kurgan 2, and skeleton 2 in grave 21 in kurgan 1, was problematic because deciduous molars, being more porous, are more likely to reflect the 'local' signal due to *post mortem* strontium uptake. More radiogenic $^{87}Sr/^{86}Sr$ values are not characteristic for the nearby Caucasus Mountains, which are mainly influenced by Mesozoic bedrock values (Fig. 4.84). Differences are only minor, and therefore probably reflect slight variations in the Precaucasian lowland geology.

The OIPC suggests $\delta^{18}O_w$ values around –10 to –9 ‰ for the area of Sukhaya Termista II, which is slightly below what the $\delta^{18}O_w$ mean of the tooth enamel suggests (Fig. 4.83). Despite the values for Sukhaya Termista II are slightly diverse in their $\delta^{18}O_w$ values, an estimated smaller 'regional' $\delta^{18}O$ range extends from –10.4 ‰ to –8.4 ‰, equivalent to the OIPC data. Samples are relatively similar in respect to $^{87}Sr/^{86}Sr$. If the wider 'local' $^{87}Sr/^{86}Sr$ range of 0.7087 to 0.7095 (2σ) is accepted, all tooth enamel results lie within the range, whereas if the outlier references are excluded, the first molars of kurgan 1 grave 5 and kurgan 3 grave 20 and the third molar of kurgan 1 grave 2 lie outside the narrower 'local' biologically available $^{87}Sr/^{86}Sr$ range of 0.709 to 0.7094 (2σ). The estimated smaller 'local' $\delta^{18}O_w$ range extends from –10.4 to –8.4 ‰, making the first molar of kurgan 1 grave 2 an outlier lying above and the third molar of kurgan 1 grave 3 lying below the range. Pooling results from the individuals with more than one sample to single symbols, all the individuals yield results within or at the border of both 'local' isotopic ranges.

All skeletons correspond to the burial traditions of the Early Catacomb culture. The marginally more depleted $\delta^{18}O_w$ value of the third molar from the female adult in kurgan1 grave 3 might be an indi-

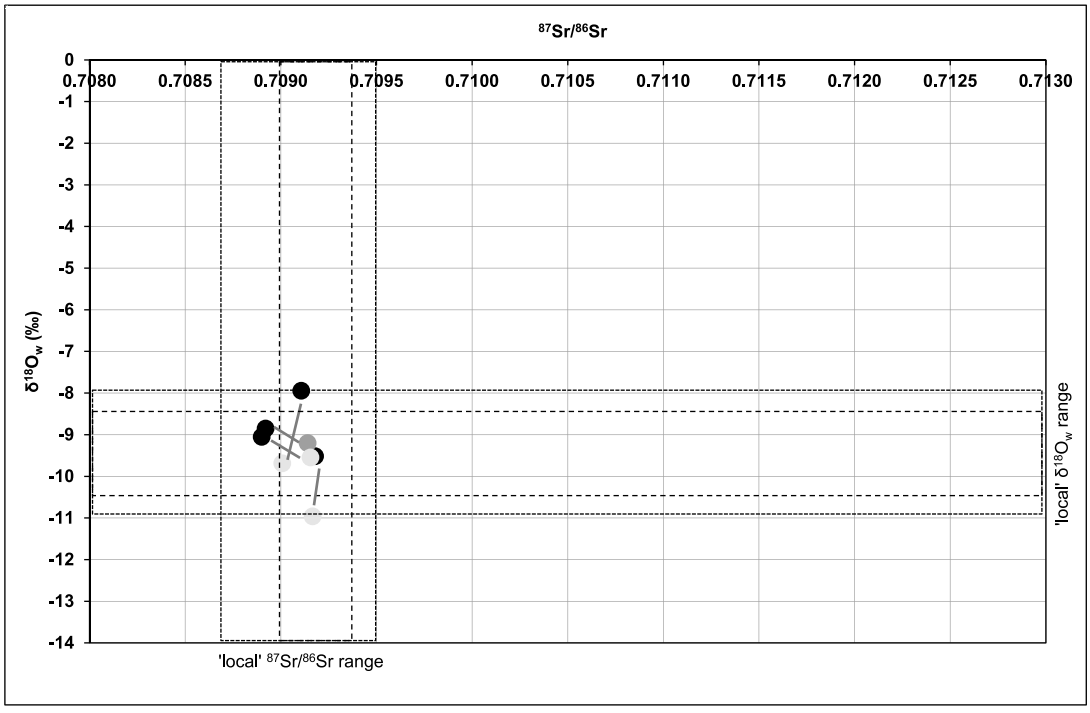


Fig. 4.83 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Sukhaya Termista II: First molars (black), second molars (dark grey), third molars (light grey). Grey lines link teeth analysed from the same individual. Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

cator for a stay in a geologically similar region with slightly depleted $\delta^{18}O$ ranges. The similarity in strontium values is to be expected where the geology is very homogeneous over a wide area. N. I. Shishlina interprets the Yamnaya communities in the northwest Caspian region to follow an annual cycle of short-distance migration, while she regards the groups of the subsequent Catacomb culture to follow migration routes extending over hundreds of kilometres (Shishlina, 2001a, 359–360; Shishlina, 2004, 101–104). The isotopic similarity of first and second or third molars sampled from the same individuals would normally suggest that their movements were fairly limited geographically, but in this case interpreting the data is difficult because the isotopic signatures are so consistent over such wide distances. It can at least be said that the isotopic data supports the suggestion that communities engaged in limited seasonal movements through an area of similar geology, with slightly varying $\delta^{18}O_w$ values.

All four individuals from Sukhaya Termista were analysed in duplicate, with the first and third molars being used for three of them and the first and second molar being used from burial 5 in kurgan 1. $^{87}Sr/^{86}Sr$ values were very similar on an intra-site and intra-individual scale and this suggests that the four individuals did not move from the same general geological region between birth and adolescence. Breastfeeding might be a possible explanation for the differences in $\delta^{18}O_w$ of burials 2 and 3 in kurgan 1. The individuals in kurgan 1 grave 5 and kurgan 3 grave 20 show increasingly enriched $\delta^{18}O_w$ values, which might be an indicator for a residence change to a region closer to the sea, further west or to a warmer region.

4.5.2 Iron Age

North Pontic region

Only the results from one individual, that from trench 15, grave 8, lies outside both the 'local' $^{87}Sr/^{86}Sr$ range of 0.7099 to 0.7104 (2σ) and the 'local' or 'regional' $\delta^{18}O_w$ range of –10.5 to –8.5 ‰ (Fig. 4.85). All human individuals sampled were placed as secondary burials in the huge Alexandropol' kurgan and dug into the periphery of the burial mound without individual grave goods. The isotopic outlier refers to the only burial of an older man; all other burials contain younger males. The isotopic ratio of the third molar from this individual is marginally more depleted in $\delta^{18}O_w$ and less radiogenic in $^{87}Sr/^{86}Sr$ than the estimated Alexandropol' range which hints to a change of location between adolescence and later life. Furthermore, the result from grave 3 in trench 10 is slightly less radiogenic than the 'local' $^{87}Sr/^{86}Sr$ range but within the 'local' $\delta^{18}O_w$ range.

The two dentine samples in Babina Mogila yield a $^{87}Sr/^{86}Sr$ mean of 0.7099, which is identical to one of the tooth enamel samples (Fig. 4.86). The estimated 'regional' $\delta^{18}O_w$ range of approximately –10.5 to –8.5 ‰ also agrees with the result from burial chamber 1, an old male that was interpreted as a 'servant' by the excavators. He might have been born in the area around the site. The skeleton in burial chamber 3 might be considered an outlier, at least in respect to its $^{87}Sr/^{86}Sr$ value. The central burial of burial chamber 3 contained a juvenile skeleton without grave goods due to robbery. This individual, if considered a real isotopic outlier, must have moved from a less radiogenic and perhaps colder or more northward region to the area around the burial place sometime between the first years of life and adolescence. Although the isotopic differences are only minor, the results might suggest that individuals of higher status were more mobile compared to those of lower rank.

Both of the tooth enamel results in Drana Kokhta fall within the limits of the 'local' $^{87}Sr/^{86}Sr$ range between 0.7094 and 0.7109 (2σ) and the 'regional' $\delta^{18}O_w$ range from –10.5 to –8.5 ‰ (Fig. 4.86). The 'local' $^{87}Sr/^{86}Sr$ range, based on two dentine measurements, however, is surprisingly wide considering the geology and compared to other sites in the same region. The strontium ratio from the juvenile, archaeologically determined female, in niche 5 is more radiogenic than the 'regional' $^{87}Sr/^{86}Sr$ range although at the time of death, the third molar sampled was still mineralising. This person may have moved to the burial site area only in the months or years before death.

The very limited 'local' $^{87}Sr/^{86}Sr$ range of 0.7098 to 0.7099 (2σ) in Ordzhonikidze encompasses only three tooth enamel values, but the remaining three values are only marginally divergent (Fig. 4.87). All tooth enamel results, apart from the female in grave 4 in kurgan 32, agree with the estimated $\delta^{18}O_w$ range for the region. Due to the minor variations in both isotope ratios, none of the skeletons can be considered a real or extreme outlier. Interestingly, the only two $^{87}Sr/^{86}Sr$ results marginally above the narrow 'local' range are the two primary burials, graves 1 and 2, in kurgan 15. This might indicate an affiliation to another community, but differences are extremely small.

The range of biologically available $^{87}Sr/^{86}Sr$ between 0.7091 and 0.7100 (2σ) in Zolotaya Balka encompasses the majority of the tooth enamel values (Fig. 4.88). Only the burials 1 in kurgan 13 and 1 in kurgan 22 lie marginally above the 'local' $^{87}Sr/^{86}Sr$ range though these two results still lie within the 'regional' $\delta^{18}O_w$ range from –10.5 to –8.5 ‰. Burial 3 in kurgan 15 yielded a more depleted result. No result lies outside both 'local' isotopic ranges. Despite the fact that the result from kurgan 15 burial 2 lies within the borders of both 'local' ranges, this individual differs in its $^{87}Sr/^{86}Sr$ value to the other samples from this site. Consequently, this individual could be regarded as an intra-site outlier. The

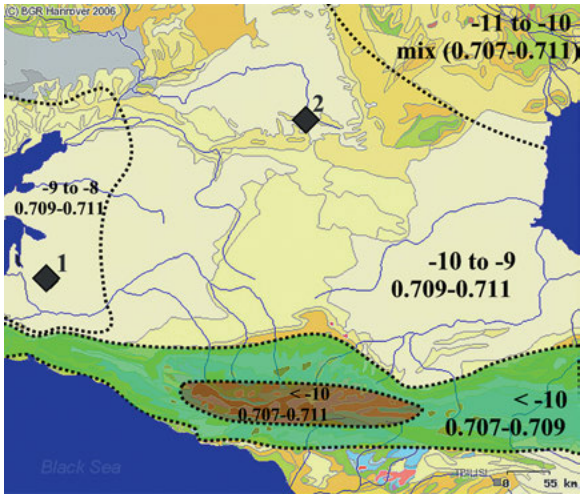


Fig. 4.84 | Geological map including estimated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (‰) ranges of the study area in southern Russia [based on Asch, 2005 and the OIPC (Bowen, 2010)]. The locations of the sites are marked by diamonds: 1 Olennii, 2 Sukhaya Termista II.

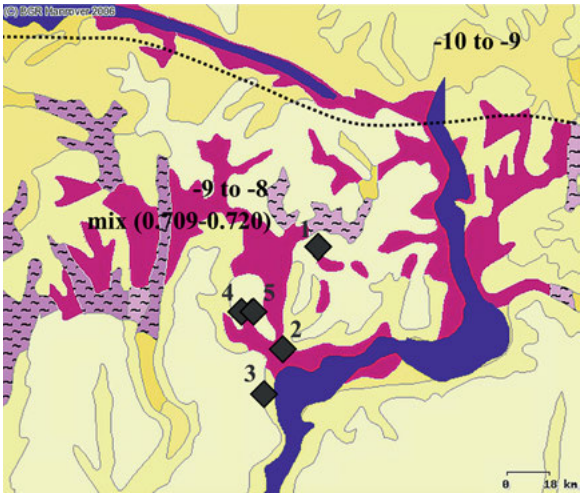


Fig. 4.91 | Geological map including estimated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (‰) ranges of the North Pontic study region [based on Asch, 2005 and the OIPC (Bowen, 2010)]. The $\delta^{18}O$ in precipitation given here is slightly less depleted compared to the estimated 'regional' range calculated from the $\delta^{18}O_w$ values in enamel. The locations of the sites are marked by diamonds: 1 Alexandropol', 2 Ordzhonikidze, 3 Zolotaya Balka, 4 Drana Kokhta, 5 Babina Mogila.

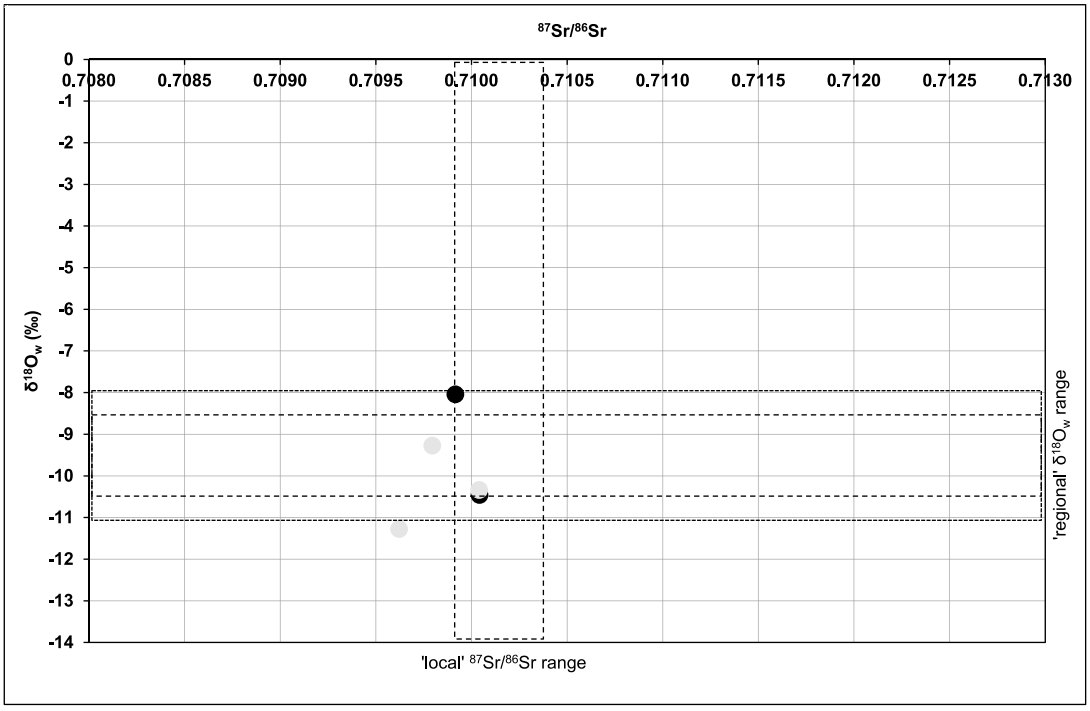


Fig. 4.85 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Alexandropol': First molars (black), third molars (light grey). Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

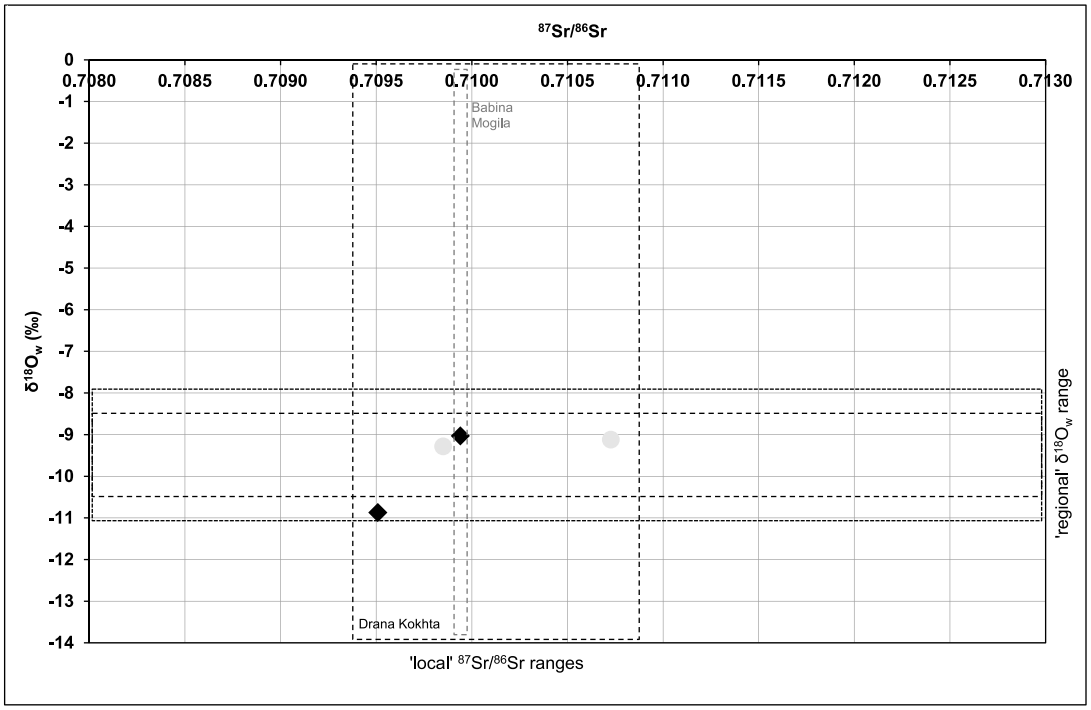


Fig. 4.86 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Babina Mogila (diamonds) and Drana Kokhta (circles): First molars (black), third molars (light grey). Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in grey and black.

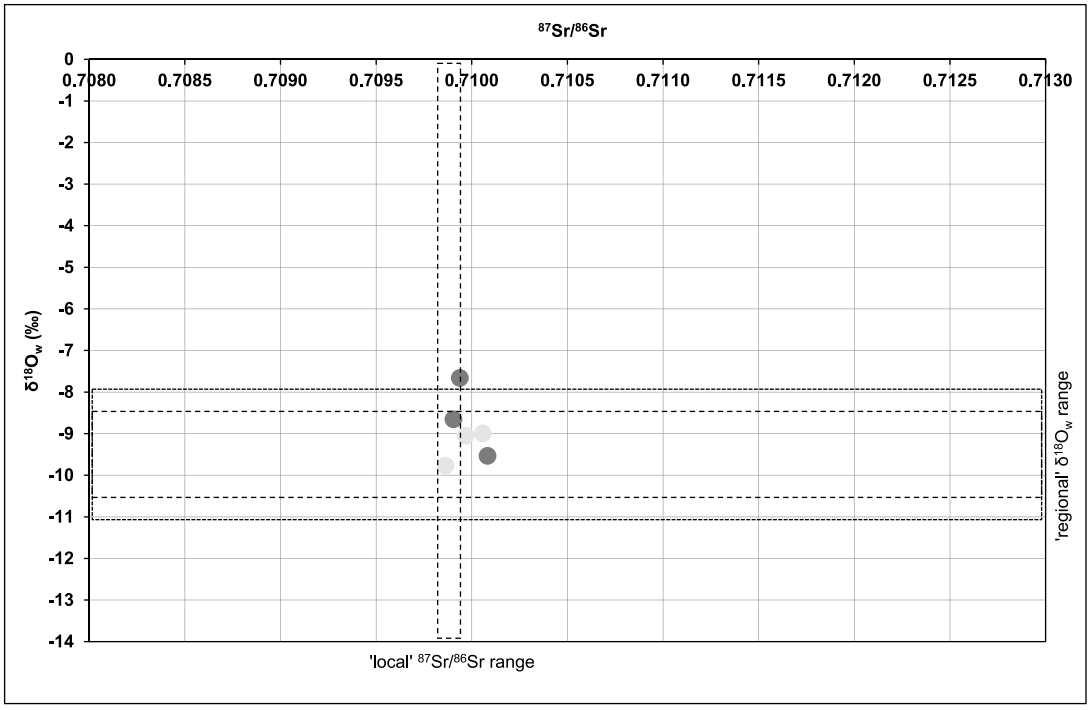


Fig. 4.87 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Ordzhonikidze: Second molars (dark grey), third molars (light grey). Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

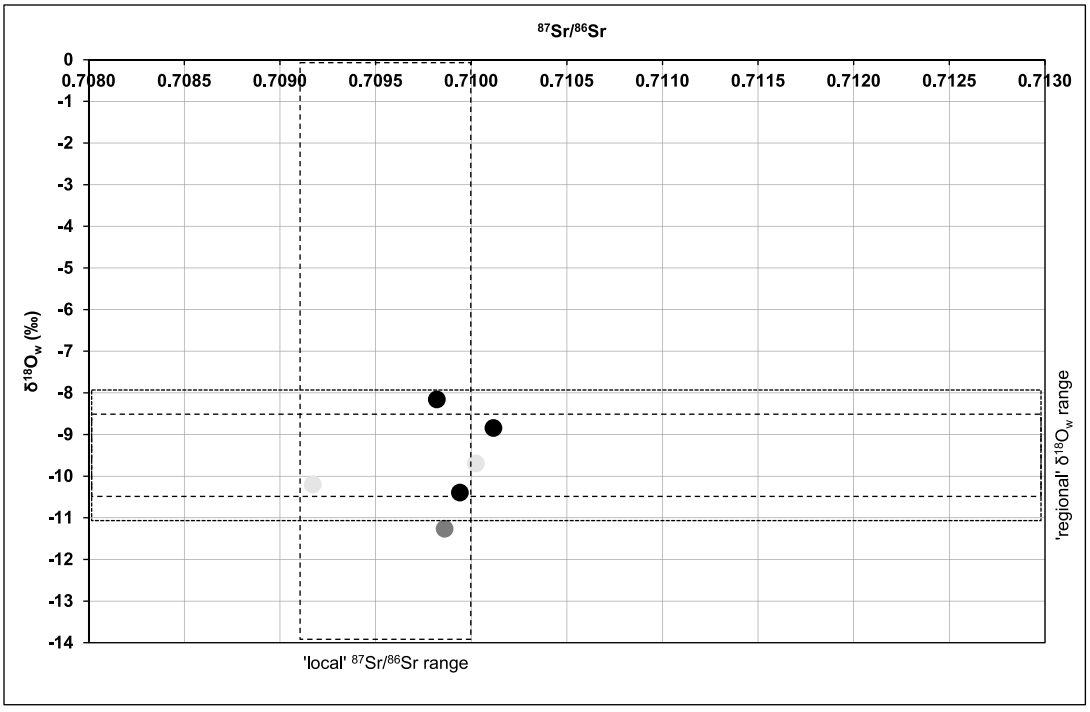


Fig. 4.88 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Zolotaya Balka: First molars (black), second molars (dark grey), third molars (light grey). Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

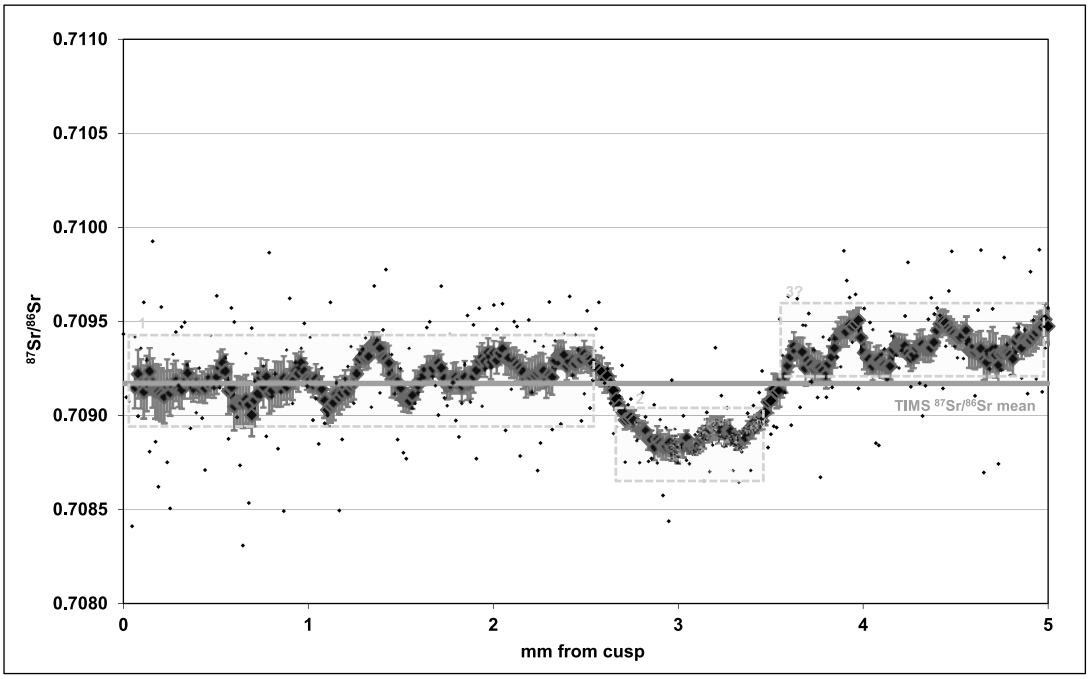


Fig. 4.89 | Data obtained by $^{87}Sr/^{86}Sr$ LA-MC-ICP-MS analysis for sample O 8 (kurgan 15 grave 2, mature male, mandubula M3), including ± 1σ. The grey line shows the $^{87}Sr/^{86}Sr$ value obtained by conventional TIMS measurement of the same tooth. Grey frames indicate potential places of residence.
LA-MC-ICP-MS analysis was performed at the National Oceanography Centre facilities at the University of Southampton. For methodological details see de Jong et al., 2010; de Jong et al., in prep.

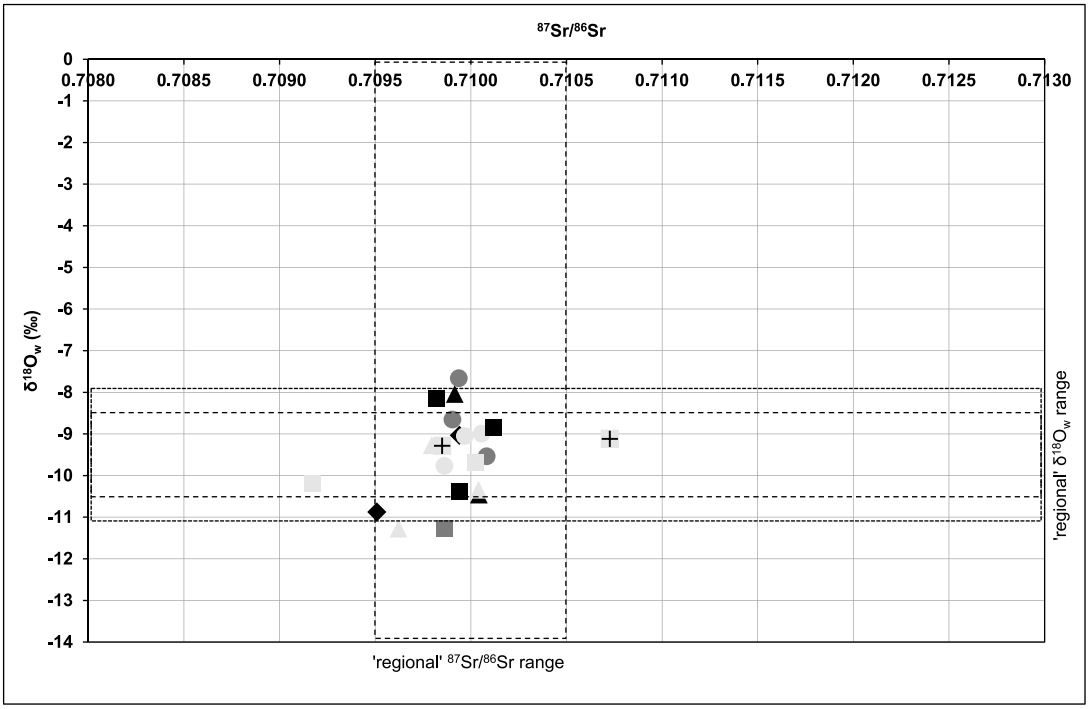


Fig. 4.90 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Alexandropol' (triangless), Babina Mogila (diamonds), Drana Kokhta (crossed squares), Ordzhonikidze (circles), and Zolotaya Balka (squares): First molars (black), second molars (dark grey), third molars (light grey). Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

burial is different to the others in that it is the only older male skeleton sampled in this group of burial mounds, but due to robbing, no further information exists for the graves. The tooth enamel from this individual was additionally analysed by $^{87}Sr/^{86}Sr$ LA-MC-ICP-MS (Fig. 4.89). The variations observed are minor and within the expected 'normal' variations typical for individuals with a limited mobility (cf. de Jong et al., 2010, fig. 2). Nevertheless, the $^{87}Sr/^{86}Sr$ values from the third molar show a pattern of three distinct potential places of residence. The individual might have lived at place 1 for some time (maybe 1 to 2 years), and then temporarily moved to another place 2 (maybe several months). Finally, the individual moved to place 3, which is characterized by similar $^{87}Sr/^{86}Sr$ values to the other individuals sampled.

The tooth enamel samples from the five North Pontic sites (Fig. 4.90) yield a narrow distribution of $^{87}Sr/^{86}Sr$ results with the majority concentrated around 0.710 and some outliers in each direction. Since the 'local' $^{87}Sr/^{86}Sr$ signature was determined in each case by two dentine samples from each of the sites Babina Mogila, Drana Kokhta and Zolotaya Balka with the addition of one animal bone from Ordzhonikidze, the individual 'local' $^{87}Sr/^{86}Sr$ signatures are somewhat uncertain. Therefore, the $^{87}Sr/^{86}Sr$ range derived from all of the reference samples from the North Pontic sites is probably the more reliable one and extends from 0.7095 to 0.7105 (2σ). According to Figure 4.91 the 'local' values from all sites should result in similar isotopic ranges. Two skeletons (Drana Kokhta niche 5, Zolotaya Balka kurgan 15 grave 2) lie outside the 'regional' $^{87}Sr/^{86}Sr$ range. The mean $\delta^{18}O_w$ of all North Pontic Scythian samples is –9.52 ± 1.01 ‰ (1σ) with a median of –9.28 ‰. This is in approximate agreement with the Central Ukrainian Eneolithic and Bronze Age mean $\delta^{18}O_w$ of –9.24 ± 1.27 ‰ (1σ) (median –9.03 ‰) based on the $\delta^{18}O_w$ values from Peshtchanka, Shakhta Stepnaya and Vinogradnoe. The marginal variations in

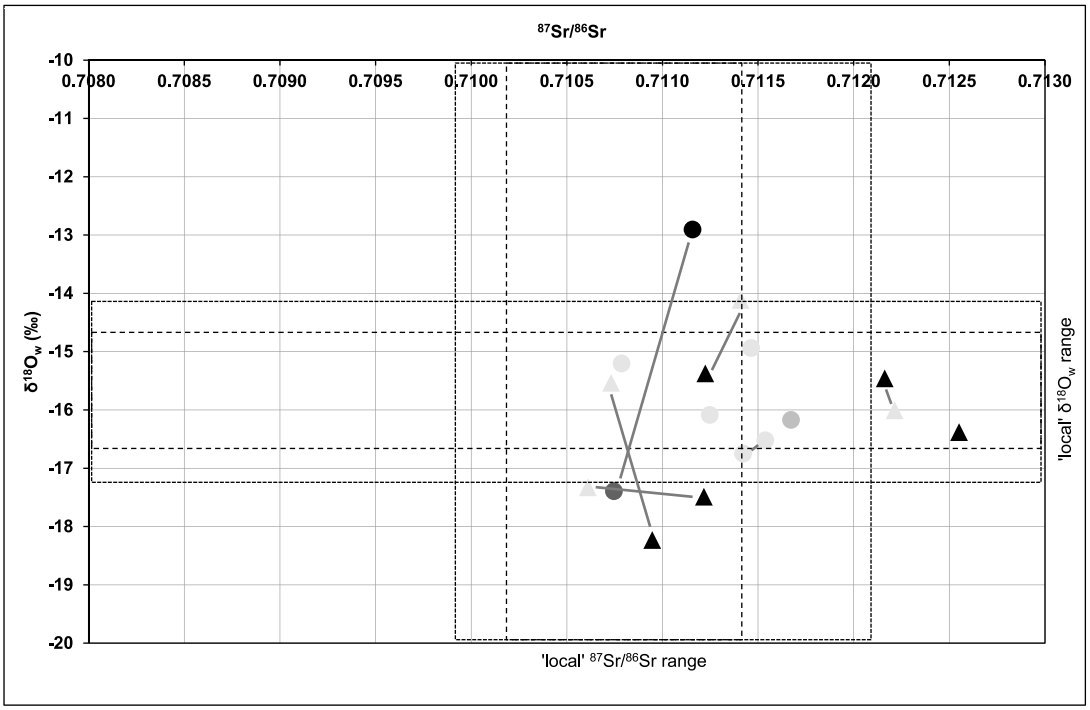


Fig. 4.93 | Integrated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values for the sampled tooth enamel from Berel'. Circles symbolize human teeth sampled: First molars (black), third molars (light grey), first premolars (light black), incisors (medium grey). Triangles symbolize sampled horse teeth: cusp (black), cervix (light grey). Grey lines link teeth analysed from the same individual. Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (using Longinelli, 1984) ranges are outlined in black.

$\delta^{18}O$ tooth enamel values between the Eneolithic/Bronze Age and the Iron Age period might suggest chronological variations in mobility patterns but may also be due to climatic differences. Based on an estimated 'regional' $\delta^{18}O_w$ range of –10.5 to –8.5 ‰ or an extended range of –11.1 to –7.9 ‰, three individuals, Alexandropol' trench 15 grave 8, Ordzhonikidze kurgan 32 grave 4, and Zolotaya Balka kurgan 15 grave 3, lie at the edge of the 'regional' $\delta^{18}O_w$ range. The majority of the tooth enamel samples, however, yielded $\delta^{18}O_w$ values that lie within the 'regional' range.

Berel' (Kazakhstan)

A geological map (Fig. 4.92) suggests that $^{87}Sr/^{86}Sr$ values at Berel' should range between 0.711 and 0.713 based on known values for Palaeozoic rocks. The reference samples yielded highly varying $^{87}Sr/^{86}Sr$ values resulting in a very wide 'local' range of 0.7099 to 0.7121, or a more narrow range of 0.7102 to 0.7114 if the outlier dentine samples are excluded. This indicates a discrepancy between the underlying geology and the biologically available $^{87}Sr/^{86}Sr$ than what might be expected by simply looking at the geological map. The $\delta^{18}O_w$ values of all Berel' samples including humans and horses average at –15.71 ± 1.35 ‰ with a median of –15.54 ‰ (Fig. 4.93). Mean $\delta^{18}O_w$ of humans (–15.74 ± 1.4 ‰) and horses (–15.68 ± 1.37 ‰) are fairly consistent. Therefore, the estimated $\delta^{18}O_w$ range is from –16.7 to –14.7 ‰ or from –17.3 to –14.1 ‰. However, this range is ambiguous as the site is situated in the mountains and a high variability of $\delta^{18}O$ values can be expected over a small vertical distance.

Both the $^{87}Sr/^{86}Sr$and the $\delta^{18}O_w$ values from the human samples are somewhat scattered. Although the samples taken from horse tooth enamel show a similar range of $\delta^{18}O_w$ values to each other, their

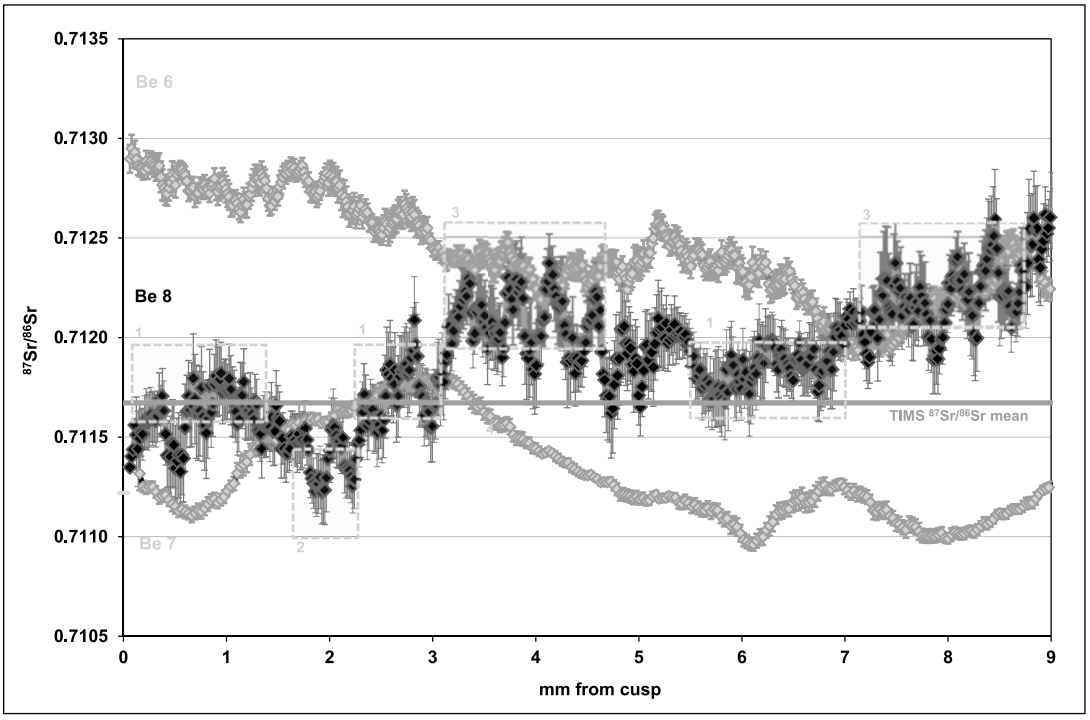


Fig. 4.94 | Data obtained by $^{87}Sr/^{86}Sr$ LA-MC-ICP-MS analysis for sample Be 8 (kurgan 34, maxilla incisor), including ± 1σ. The grey line shows the $^{87}Sr/^{86}Sr$ value obtained by conventional TIMS measurement of the same teeth. Grey frames indicate potential places of residence.
LA-MC-ICP-MS analysis was performed at the National Oceanography Centre facilities at the University of Southampton. For methodological details see de Jong et al., 2010; de Jong et al., in prep.

$^{87}Sr/^{86}Sr$ ratios are more scattered. The human skeletons in kurgans 9, 10 and 16 yielded results that lie within the 'local' $^{87}Sr/^{86}Sr$ range. The human individuals in kurgans 32, 34 and 72 yielded marginally more radiogenic strontium ratios. Furthermore, the samples from the humans in kurgans 10 and 32 (M3) do not agree with the 'local' $\delta^{18}O_w$ range. Surprisingly, the sampled humans in kurgans 10 and 16 yielded similar isotopic results, even though the kurgans belong to different kurgan lines. The two human individuals, for which two $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values were obtained, showed differing results. The human in kurgan 32 probably stayed at the same locality, while a change of place during the first years of life could be suggested for the individual in kurgan 10. All the sampled skeletons were primary burials with an extensive selection of grave goods. Further interpretations are difficult to make, since it remains unclear which of the humans in the kurgans were selected for analysis.

The incisor from the individual in kurgan 34 underwent analysis by laser ablation (LA-MC-ICP-MS) (Fig. 4.94). Incisors reflect the isotopic signal of the first 3 to 5 years of an individual's lifetime. The laser data suggests that this individual was highly mobile between regions with very different $^{87}Sr/^{86}Sr$ ratios and stayed at least twice at places with the same or similar $^{87}Sr/^{86}Sr$ signatures (places 1 and 3). The $^{87}Sr/^{86}Sr$ values suggest these places to be in mountain areas with the possible exception of place 2. Transhumance is certainly one explanation for these findings, though of course not the only one.

Results from the horses in kurgans 9, 10 (partially) and 11 (most radiogenic) lay outside the $^{87}Sr/^{86}Sr$ range, whereas the $\delta^{18}O_w$ values from the horses in kurgans 18 (cusp), 23 (cusp and cervix), and

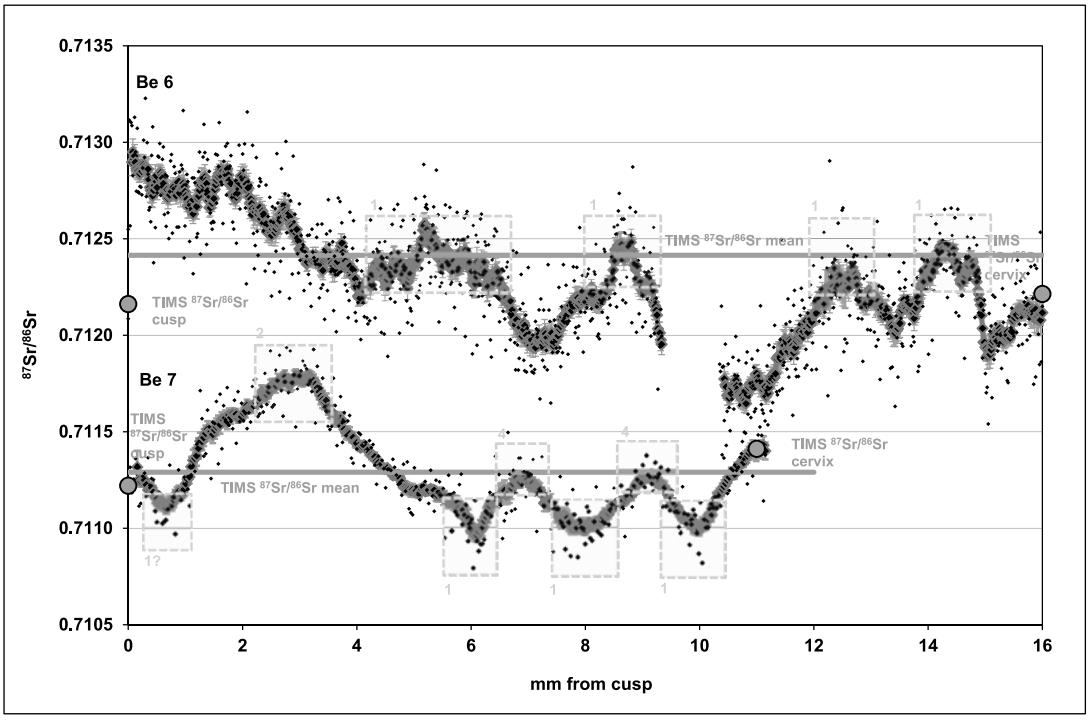


Fig. 4.95 | Data obtained by $^{87}Sr/^{86}Sr$ LA-MC-ICP-MS analysis for sample Be 6 (kurgan 9, horse) and Be 7 (kurgan 10, horse), including ± 1σ. The grey lines show the $^{87}Sr/^{86}Sr$ value obtained by conventional TIMS measurement of the same teeth. Grey frames indicate potential places of residence.
LA-MC-ICP-MS analysis was performed at the National Oceanography Centre facilities at the University of Southampton. For methodological details see de Jong et al., 2010; de Jong et al., in prep.

10 (cervix) lay outside the expected $\delta^{18}O_w$ range. This makes the horses from kurgans 10, 18 and 23 outliers according to their $\delta^{18}O$ values. The $\delta^{18}O_w$ values from the horses in kurgans 10, 18 and 23 (and the $^{87}Sr/^{86}Sr$ values for the latter) are dissimilar and indicate seasonal movement, a single change of place, or they might indicate differences in oxygen isotope ratios due to naturally occuring seasonal variations. The most obvious isotopic outliers in $^{87}Sr/^{86}Sr$ values were the horses in kurgans 9 and 11. They were completely different to any of the human individuals. Two horse teeth, the one from kurgan 9 and the one from kurgan 10, were analysed by $^{87}Sr/^{86}Sr$ laser ablation LA-MC-ICP-MS analysis in addition to conventional TIMS analysis (Fig. 4.95). Both horses show changing patterns of $^{87}Sr/^{86}Sr$ values with repeated stays at the same or a similar $^{87}Sr/^{86}Sr$ province. The amount the $^{87}Sr/^{86}Sr$ values variation is only minor, however, particularly in the horse from kurgan 10. Nevertheless, the data suggests that the horses did not stay in one single $^{87}Sr/^{86}Sr$ province but moved around frequently. This might be due to transhumant herding activities or for other reasons. Repetitive stays in isotopically similar regions, however, point to mobility in association with circular or repeated movements. It seems that the horse from kurgan 10 came back to the same or a similar $^{87}Sr/^{86}Sr$ province after a temporary stay at another place. This could possibly be explained by one-time movements, and one could think of trade, warfare or surveys to explore unknown environments.

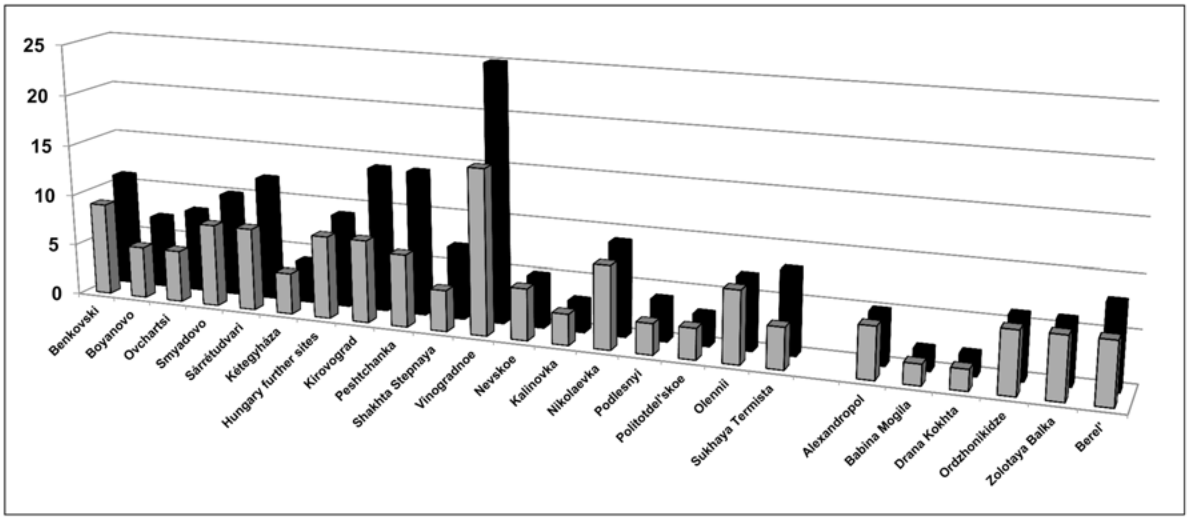


Fig. 4.96 | Selected samples per site: number of human individuals sampled (grey columns) and number of tooth enamel samples (black columns).

4.6 Discussion of this chapter's results

4.6.1 Sampling

4.6.1.1 Sample selection and sample size

It is undisputed that core tooth enamel is the material of choice for both $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses. In $^{87}Sr/^{86}Sr$ provenance studies the first molar (M1) is commonly selected due to its mineralisation period early in life. In the last couple of years, however, a debate has developed as to whether the use of second (M2) or third molars (M3) would be preferable. Third molars are the preferred material in $\delta^{18}O$ analysis because, in contrast to M1 and potentially M2, they are not altered through breastfeeding (e.g. Wright/Schwarcz, 1998; White et al., 2004a; Tütken, 2010, 40). In the present study first molars (and additionally third molars) were preferentially chosen for analysis but sample selection was restricted by availability. In order for the same time frame to be analysed, samples for both strontium and oxygen isotope analyses were taken from the same tooth, regardless of the problems associated with first molars in $\delta^{18}O$ analysis. Effective statistical analysis of any material requires the collection of a certain number of samples as a basis of any 'watertight' analysis and conclusion. Moreover, it is necessary to have sufficiently large sample sizes from different gender, age and chronological groups. In the present study, samples were selected according to availability and so these requirements were often not met. Sample sizes per site range between two samples taken from two individuals in Babina Mogila and Drana Kokhta to 25 samples taken from 16 individuals in Vinogradnoe (Fig. 4.96), but the average number of teeth sampled per site does not exceed 7.9 taken from 5.9 individuals. Therefore, sample sizes often only amount to one or two when broken down to age, gender or chronological group per site.

The analysis of a plausible number of samples for statistical analysis over such a vast area goes beyond the scope of this study in both the cost and time needed to carry out such an extensive analysis.

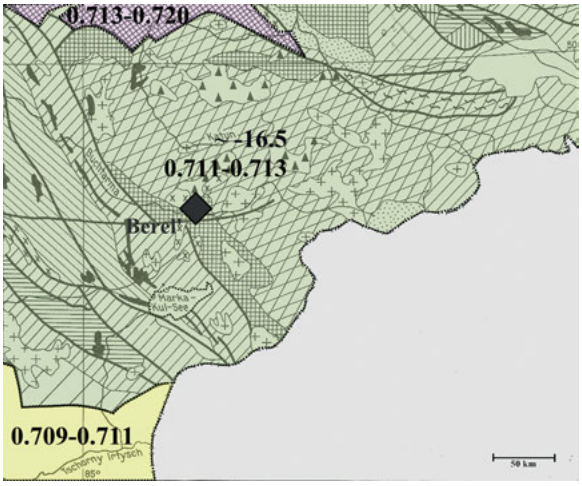


Fig. 4.92 | Geological map of the Berel environment and estimated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ (‰) ranges (modified after Nechoroschew, 1966, Fig. 18, $\delta^{18}O$ in precipitation based on the OIPC). The location of the site is marked by a diamond.

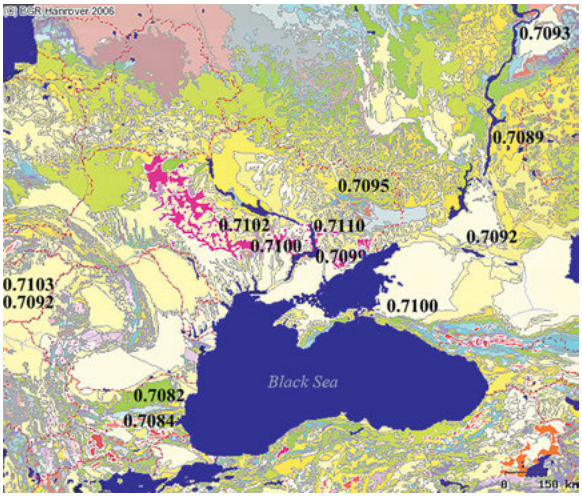


Fig. 4.97 | Geological map of the study area (based on Asch, 2005) with measured mean values of the reference samples from each study site. The site Berel' is excluded. No standard deviations are given. Cenozoic (yellow): ~ 0.709–0.711, Mesozoic (green, purple, turquoise): ~ 0.707–0.709, Palaeozoic (grey, rust brown): ~ 0.711–0.720, Proterozoic metamorphic rock (pink): > 0.712.

It is therefore advisable to select fewer sites, which offer suitable numbers of samples for statistical analysis.

4.6.1.2 Reference sample material and the definition of the 'local' signatures

The selection of reference sample material is heavily debated and has been the subject of a number of studies (e.g. Price et al., 2002; Bentley, 2006; Brandt et al., 2010; Evans et al., 2010) as discussed in Chapter 4.3.1.3. As recognized by other studies, the local geology is a solid base from which to start in the case of $^{87}Sr/^{86}Sr$ analysis (Grupe et al., 1997, 520; Vohberger, 2011, 144), although the composition of the bedrock and the overlying weathered sediments are not the only variables, which complicate the comparison of different regions. In the present study, soil samples were taken from a number of sites. Most of the soil samples agreed with the expected $^{87}Sr/^{86}Sr$ ratios from the underlying geology (Fig. 4.97). At Benkovski the $^{87}Sr/^{86}Sr$ values were lower than expected and at Sárrétudvari the $^{87}Sr/^{86}Sr$ values were higher. The soil samples were collected in areas near cultivated fields, therefore both of these differences might be explained by modern contamination of the soils through the use of fertilisers, for example.

Loess can have extremely variable $^{87}Sr/^{86}Sr$ values depending on the origin of the loess. The loess in the Carpathian Basin, which was analysed by Újvári and colleagues, for example, has relatively high values (around 0.71256 and 0.71524) (Újvári et al., 2010), although this was bulk loess. Biologically available Sr in that region is much lower (cf. Giblin, 2004; Giblin et al., 2009). In this study, soil samples in loess regions yielding values above this range came from sites with mixed Cenozoic and Proterozoic geology. This shows that the $^{87}Sr/^{86}Sr$ values of loess measured in one region cannot simply be ascribed to other regions. In the study area, soil samples from areas of pure Cenozoic sediments gave results

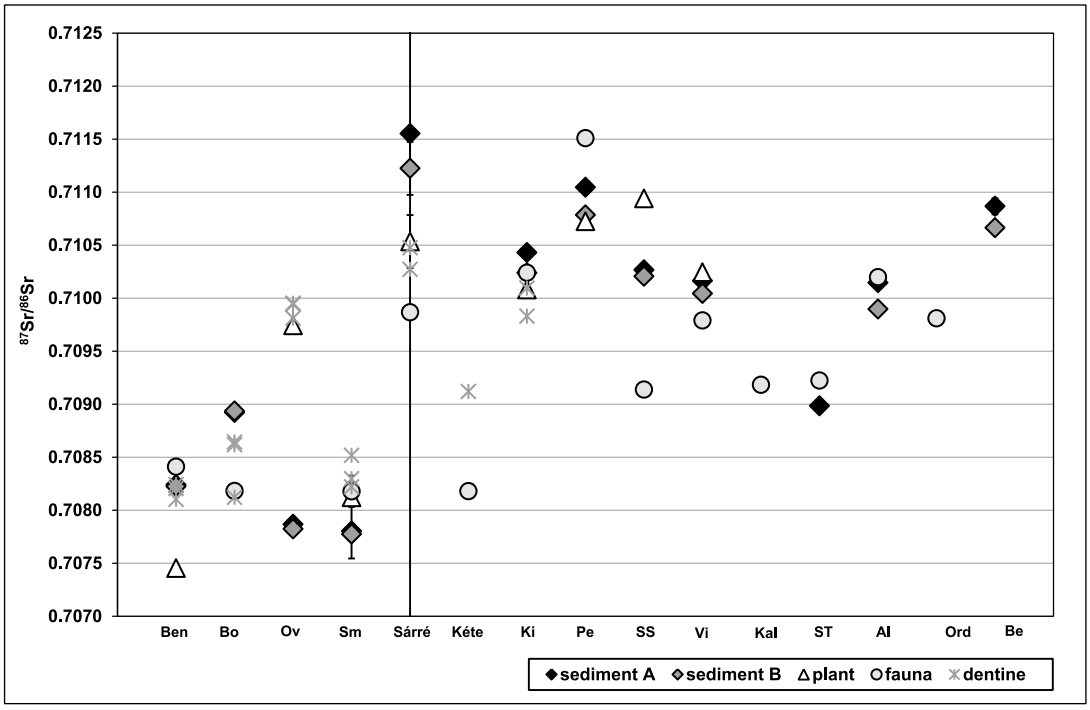


Fig. 4.98 | $^{87}Sr/^{86}Sr$ data for the reference material from the sample sites (sediment A = water leachates of soil, sediment B = acid leachates of soil).

between 0.709 and 0.7103. Soil samples alone, however, do not necessarily represent the biologically available $^{87}Sr/^{86}Sr$ at a specific site. Nevertheless, several studies have shown that soil and the underlying solid geology have similar $^{87}Sr/^{86}Sr$ signatures (e.g. Hodell et al., 2004). In this study, leachates of sediments generally agreed with other reference material such as fauna and plant samples (Fig. 4.98) and the mean $^{87}Sr/^{86}Sr$ values of the reference samples mainly agree with the underlying geology (Fig. 4.97). Sediments were in accord with other samples at Smyadovo, Kirovograd, Peshtchanka and Vinogradnoe and at Benkovski, Shakhta Stepnaya and Alexandropol', where faunal material formed additional reference samples. There was not such a good match between soil and other reference samples at Boyanovo, Ovchartsi, Sárrétudvari and Shakhta Stepnaya.

Price et al. (2002) and Bentley (2006) defined the 'local' isotopic signature' by suggesting that samples should be taken from local archaeological and recent fauna, soil, plants and water supplies. According to the authors, each type of reference sample has advantages and disadvantages. With this in mind, a selection of various reference materials including teeth from small mammals, snail shells, soil and plant materials should ideally be selected for comparison in $^{87}Sr/^{86}Sr$ analysis. Samples taken should preferably derive from contemporaneous contexts and should not be contaminated by modern environmental factors such as fertilizers. Bentley et al. (2004) suggest calculating a ± 2 standard deviation range around the mean $^{87}Sr/^{86}Sr$ value of reference faunal samples and recommend selecting single animal species for the calculation of the local range, while at their study sites at Bury Hill and Rooksdown, Bendrey et al. (2009, 146) calculated a ± 2 standard deviation frame around the mean $^{87}Sr/^{86}Sr$ value of all reference material collected due to the small number of samples.

The conventional approach to defining the 'local' $^{87}Sr/^{86}Sr$ signature by taking the mean of the combined reference samples and adding two standard deviations is currently contested, however, as it leads to relatively low and implausible numbers of outliers. In Wenigumstadt, for example, Vohberger classified only 5.1 % of the individuals as outliers when applying this approach, while palaeodemography assumes that 10 % of the population were not buried near their homeland due to migrations by marriage, trade or for other reasons (Vohberger, 2011, 142).

Although in the present study most samples derived from recently excavated sites, the collection of reference sample material was relatively complicated. In the majority of cases animal remains from the excavations were not stored. Therefore, between 2008 and 2010 sediments, plants, modern rodents and snail shells were collected from the sites in southern Central Ukraine and Bulgaria. Reference sample material was also collected at Berel' in Kazakhstan (Be), at Sárrétudvari in Hungary (Sárré) and at Sukhaya Termista II (ST) in Russia. The combination of a range of reference types was found to be useful. In most cases, the different types of samples gave consistent results. Modern contamination was the most likely cause of results lying outside the range of other reference samples. Figure 4.98 details the reference sample material used at each site. At several sites a combination of sediments, plants and fauna was selected for analysis. At four sites [Smyadovo (Sm), Kirovograd (Ki), Peshtchanka (Pe) and Vinogradnoe (Vi)] all types of reference samples gave generally consistent results, though at Vinogradnoe two samples were not consistent with other reference samples. At the two sites of Sárrétudvari and Shakhta Stepnaya (SS), reference samples had a much wider distribution. Contamination by modern pollution, for example, could be an explanation for discrepancies in the reference sample material. According to Price et al. (2002) archaeological small mammals with a locally restricted habitat are to be preferred for reference material and Bentley (2006) recommended the use of snail shells. In other studies (e.g. Vohberger, 2011, 143–144, 166), snail shells gave relatively low results compared to the sediment, while water, sediment and faunal samples gave consistent results. In the present study, rodent teeth and snail shells proved on the whole to be a good proxy for the biologically available Sr at the site. Congruencies between faunal samples and sediments were observed for five sites [(Benkovski (Ben), Smyadovo, Kirovograd, Sukhaya Termista and Alexandropol' (Al)], but there were also major differences between faunal samples and other references at some sites (Sárrétudvari, Shakhta Stepnaya, outliers at Vinogradnoe).

The use of plant references to establish the 'local' $^{87}Sr/^{86}Sr$ range was suggested by a number of authors (for example Brandt et al., 2010, 27–29). Plants were used as reference material in multiple studies and achieved acceptable results (for example Towers et al., 2010; Viner et al., 2010). Plant material showed results consistent with other reference samples, except for three sites [Benkovski, Ovchartsi (Ov), Shakhta Stepnaya]. Here, again, outlier values could be explained by modern contamination.

As discussed in Chapter 4.3.1.3, tooth dentine and bone do not make ideal reference material. Post depositional absorption of strontium from the burial environment means that bone and dentine may be used to provide an estimate for the 'local' $^{87}Sr/^{86}Sr$ ratios (Budd et al., 2000; Trickett et al., 2003) and these body tissues have been used in other studies (Beard/Johnson, 2000; Montgomery et al., 2007b; Bendrey et al., 2009, 146), but the rate of absorption is not constant and varies with different environments so in some cases there could be a only partial replacement. Lack of other suitable reference material in some cases however made it necessary to use bone and dentine to establish the 'local' $^{87}Sr/^{86}Sr$ ranges. At sites in the Middle Volga region, where no further reference material was available despite two animal bones from Kalinovka I (Kal), at Olennii in the Kuban region and at Nevskoe in Eastern Ukraine, bone and/or dentine were used to establish the 'local' $^{87}Sr/^{86}Sr$ range.

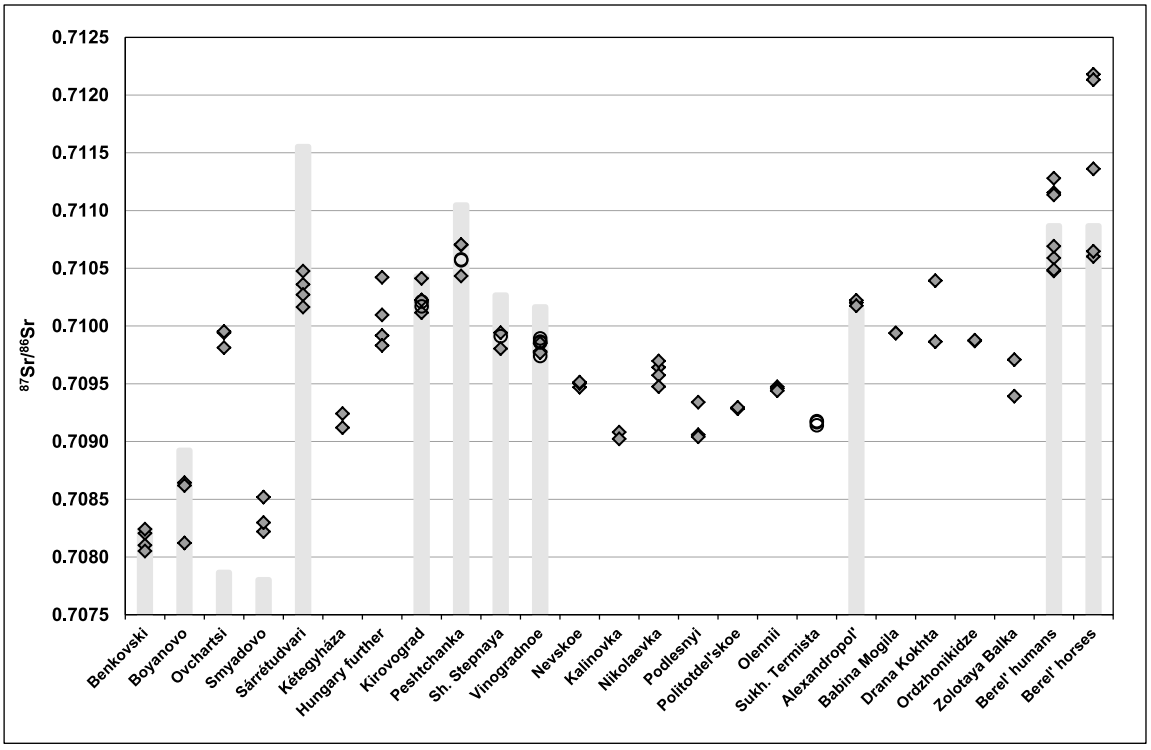


Fig. 4.99 | $^{87}Sr/^{86}Sr$ data for dentine (diamonds), bone (circles) and mean of aqueous leachates of soil (columns) from each site. No standard errors were added.

At all four sites in southern Central Ukraine and at Sukhaya Termista II dentine and bone were included in the pool of reference samples from other sites in order to test their reliability. In cases where the 'local' $^{87}Sr/^{86}Sr$ signal was based solely on samples from dentine, however, the resulting ranges were for the most part excessively restricted, as in Nevskoe and Olennii for example. Figure 4.99 shows that the $^{87}Sr/^{86}Sr$ values from several dentine samples at each site are relatively consistent despite very different enamel values. Dentine samples from Benkovski, Kirovograd and Alexandropol' were found to give consistent results both between themselves and when compared to the soil samples from the same sites. Soil samples gave slightly higher $^{87}Sr/^{86}Sr$ results in Peshtchanka, Shakhta Stepnaya and Vinogradnoe, although there was consistency among the dentine and bone samples. There was no agreement between dentine and soil samples in Ovchartsi, Smyadovo and Sárrétudvari, though the results from the dentine clustered tightly. At all three of these places, soil samples were taken from cultivated fields and not from the vicinity of the former burial mounds. Furthermore, the dentine matched the other reference samples analysed such as plants and fauna (Fig. 4.98). Therefore, in these cases, dentine was found to be more reliable as a reference material. The inconsistencies between soil and dentine samples at the site of Berel' might be explained by the burials of the skeletons in wooden sarcophagi covered by stone mounds. In this case, it would not be expected that the dentine should be affected by post-mortem contamination from the soil. Furthermore, it is possible that permafrost might preserve the original isotopic ratios of the dentine. To conclude, where dentine could be compared to soil it has been proven to be a relatively good reference material contributing in establishing a 'local' signature. Nevertheless, the pattern of tight clusters from dentine sampling indicates that 'local' $^{87}Sr/^{86}Sr$ ranges based on dentine

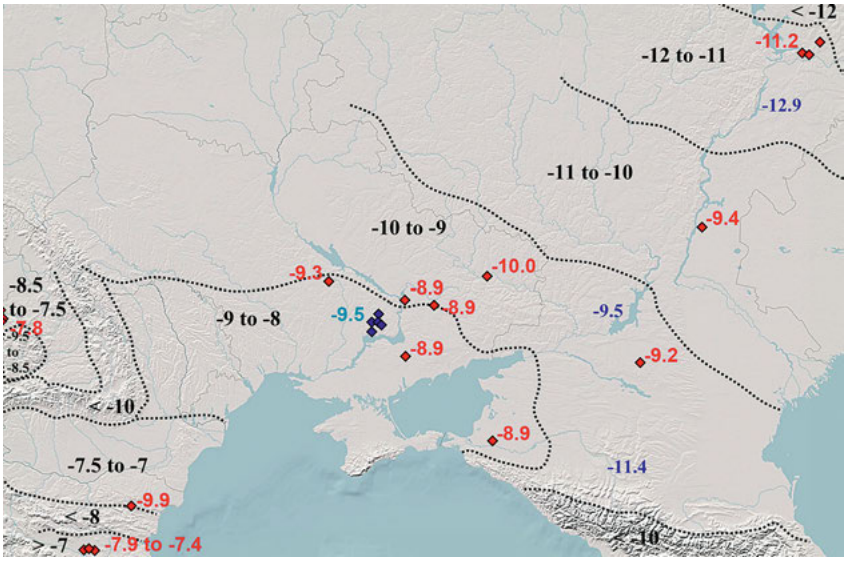


Fig. 4.100 | Approximate expected $\delta^{18}O_w$ (‰) ranges in the study region [based on the OIPC (Bowen, 2010)] and location of the study sites: Eneolithic and Bronze Age (red symbols), Iron Age (blue symbols). The site Berel' is not mapped.

alone will be too narrow. This study has shown that although dentine and bone reflect the isotopic signature of the burial environment, they do also correspond to the biologically available strontium in most cases and are therefore not the worst choice when establishing a 'local' $^{87}Sr/^{86}Sr$ range in the absence of other reference material.

Establishing a reliable 'local' $\delta^{18}O_w$ range is even more challenging. According to Brandt et al. (2010, 27–29), samples of modern water and archaeological fauna should be selected for reference sampling. Changes in climate and metabolic processes have to be taken into account when sampling these materials. Vohberger (2011, 170) also favours the definition of the 'local' $\delta^{18}O$ range using samples from locally restricted living archaeological humans and animals. Using the established equations as given in Coplen (1983), values can be compared between $\delta^{18}O_{carbonate}$ (V-PDB) and $\delta^{18}O_{carbonate}$ (V-SMOW). The conversion equation of Iacumin et al. (1996) enables the calculation of $\delta^{18}O_{phosphate}$ (V-SMOW) from $\delta^{18}O_{carbonate}$ (V-SMOW). For humans, the equations given in Longinelli (1984), Luz et al. (1984), Levinson et al. (1987), Daux et al. (2008) and Pollard et al. (2011a) can be used to convert data into $\delta^{18}O_{water}$ which is comparable to $\delta^{18}O$ in modern precipitation (but cf. also critical review in Pollard et al., 2011a). A direct calculation of $\delta^{18}O_c$ into $\delta^{18}O_w$ was published by Chenery et al. (2012) only recently. In the present study no reference samples of modern water or archaeological fauna were obtained to establish the 'local' $\delta^{18}O_w$ ranges. Results from a study by Iacumin et al. 2004 (a, b) were used as the basis for comparison in the absence of other reference samples and were consistent with the data from the present study to some degree. Conflicting results might be explained by chronological and spatial variations. Other authors have acknowledged these complications and Pellegrini et al. (2008, 1716) suggest that $\delta^{18}O$ data should be interpreted on a site-by-site basis in order to exclude time- and location-dependent variables and include variables that are specific to the site. Vohberger (2011, 170–171), for example, used three strands of evidence to establish the 'local' $\delta^{18}O_w$ range for her study in Wenigumstadt. Firstly, she used the $\delta^{18}O_w$ values from all individuals in her study, then

she used those from individuals that were considered to be outliers based on their $^{87}Sr/^{86}Sr$ results and finally she used the Excel macro Isoplot. Due to the small sample sizes attained, this approach could not be applied to the present study. Therefore, the best approach seemed to be to calculate the mean $\delta^{18}O_w$ value of all sampled individuals and compare with the OIPC values for the study regions with the addition of 1 ‰ to 1.59 ‰ standard deviations (cf. Chapter 4.4.5.1). Figure 4.100 shows that the measured mean $\delta^{18}O_w$ values of the enamel samples agree extraordinary well with modelled values in the study area based on the OIPC (Bowen, 2010), which shows that is indeed very useful to apply this tool for $\delta^{18}O_w$ modelling.

4.6.1.3 Intra-individual sampling in humans

According to availability, a number of individuals were sampled in duplicate for $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses to look at changes of residence during infancy and adolescence (Fig. 4.101a, b; see also Chapter 4.5 for discussion of the results). Generally, first or second molars were compared with second or third molars covering a time span from birth to late adolescence. Some individuals had similar $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values for both sampled teeth while others had contradictory results in that only one of the $^{87}Sr/^{86}Sr$ or $\delta^{18}O$ values indicated another place of residence. In cases where the $\delta^{18}O$ value in the first molar was significantly less depleted than in the second or third molar but $^{87}Sr/^{86}Sr$ values were comparable, discrepancies were assumed to stem from the interference of a breastfeeding signal. Intra-individual variation was generally higher in $\delta^{18}O$ than in $^{87}Sr/^{86}Sr$.

In conclusion, it could be shown that $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses from more than one tooth per individual offer an extremely useful tool in obtaining more detailed information on mobility and migration than the analysis of only one tooth per individual. The observed residence changes for two individuals at Boyanovo would have remained undetected if only one tooth per individual had been analysed.

4.6.2 Identification of outliers

4.6.2.1 'Local' or 'non-local'?

$^{87}Sr/^{86}Sr$ and $\delta^{18}O$ isotopic signatures are not unique and occur over wide ranges and at multiple places. The combination of the two methods can help to exclude some areas that cannot be distinguished by the analysis of isotopes from only one element. Combined with the archaeological evidence, oxygen and strontium isotope analyses make three independent variables, which can suggest the regions of origin of single individuals. At best, all three variables will combine to indicate an origin from a certain region; while at worst none of the variables will agree and point to different regions of origin. Possible combinations of indicators of the foreign origin of an individual are illustrated using samples dating to the Developed Catacomb culture from Vinogradnoe (Fig. 4.102a) and Early Bronze Age burials from Sárrétudvari (Fig. 4.102b).

At Vinogradnoe, example A refers to the mature male individual in grave 17 in kurgan 24, where the burial tradition, very depleted $\delta^{18}O$ and a constant $^{87}Sr/^{86}Sr$ value point to another region of origin. This area might be located further north. Burial 26 in kurgan 24 can count as example B, where the $^{87}Sr/^{86}Sr$

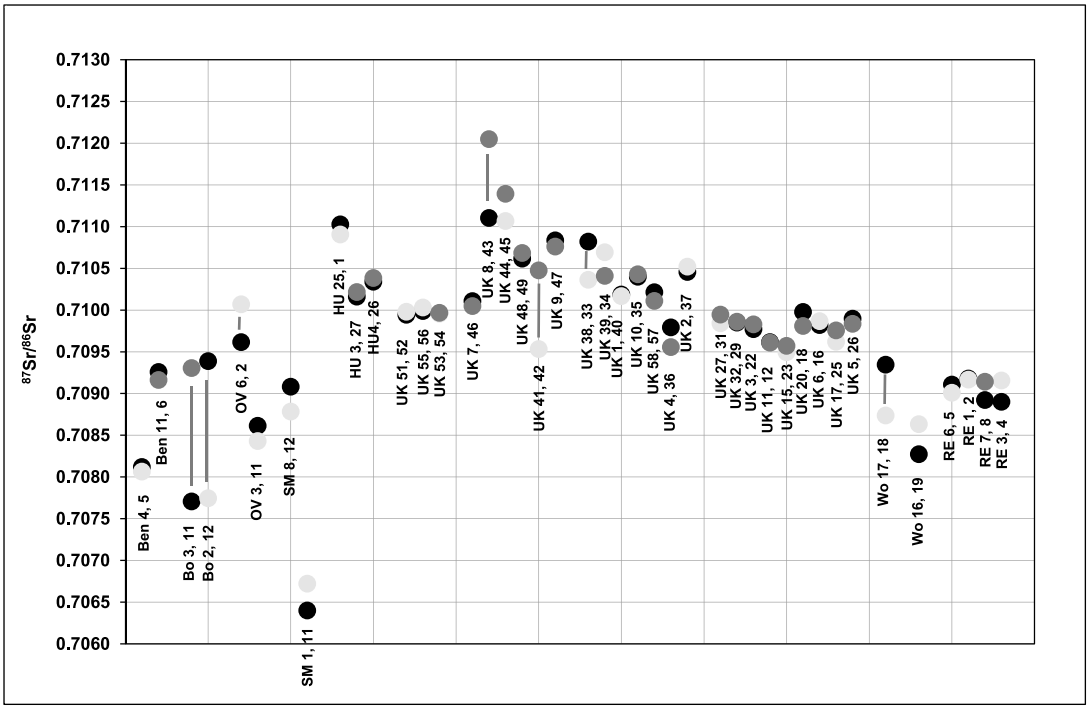


Fig. 4.101a | Results for $^{87}Sr/^{86}Sr$ analysis for the human individuals sampled in duplicate: First molars (black circles), second molars (dark grey), third molars (light grey). The graph shows only skeletons, of which two molars were analysed. Teeth from the same individual are arranged in a line.

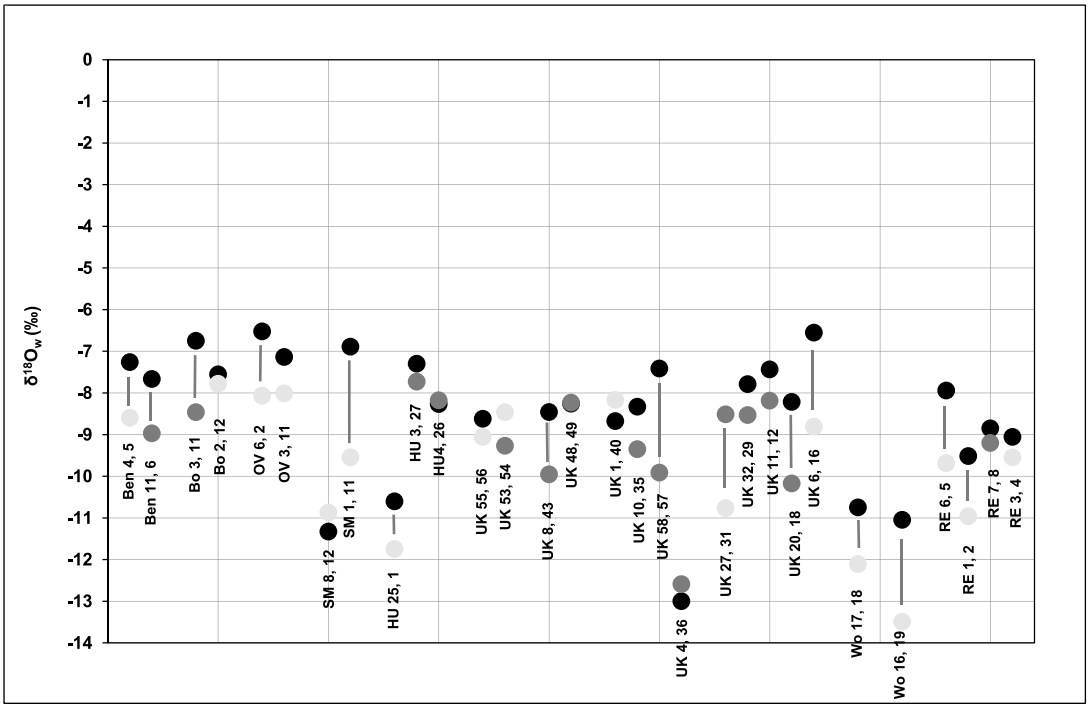


Fig. 4.101b | Results for $\delta^{18}O$ analysis for the human individuals sampled in duplicate: First molars (black circles), second molars (dark grey), third molars (light grey). The graph shows only skeletons, of which two molars were analysed. Teeth from the same individual are arranged in a line. $\delta^{18}O_{water}$ was calculated using Longinelli, 1984.

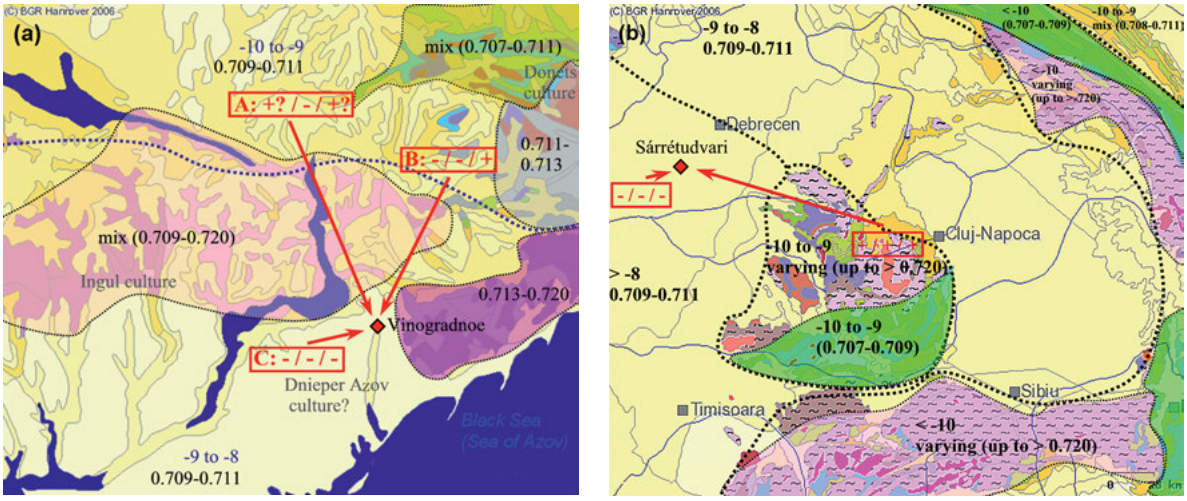


Fig. 4.102 | Possibilities of 'local' and 'non-local' identification in the North Pontic region (a) and the East Hungarian Plain (b) using archaeological and strontium and oxygen isotope evidence (referring to the model in Tütken, 2010, 45 fig. 6).

values are local but $\delta^{18}O$ values differ. There are no burial objects. Therefore, this individual might be an example of – / – / +, but it might also correspond to + / – / +. Example C, the mature male individual in grave 32 in kurgan 24, might have originated at the site or several dozen kilometres away although neither the burial tradition nor the $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values differ so that this individual cannot be identified as an outlier.

At Sárrétudvari-Őrhalom the buried individuals form two clusters. The first cluster is characterised by 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values in combination with non-differing burial objects (– / – / –), while the second cluster of individuals feature 'foreign' burial objects and stable isotope values (+ / + / +). Example A, the mature male individual in grave 10 can count for the first cluster, whereas example B, the mature male individual in grave 7, is a good representative of the second cluster.

4.6.2.2 Identification of outliers on an intra-site level

Table 4.13 shows the numbers of outlier individuals in respect to either $^{87}Sr/^{86}Sr$ or $\delta^{18}O$ values or both isotopic ratios. No site has an outlier proportion of more than 50 % in both $^{87}Sr/^{86}Sr$ and $\delta^{18}O$. The highest proportion of $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ outliers was found in the individuals from Podlesnyi (50 %), followed by Sárrétudvari-Őrhalom and Smyadovo with slightly lower percentages. The highest proportions of outliers in $^{87}Sr/^{86}Sr$ (> 50 %) were found at Kirovograd, all sites located in the Middle Volga region and possibly Boyanovo. The two sites with a high $\delta^{18}O_w$ outlier proportions (> 50 %) are Smyadovo and Podlesnyi.

As already mentioned, the type of reference sample materials and their reliability differs between the sites so the distinction between locals and non-locals is certainly not indisputable. The relatively high outlier percentages for $^{87}Sr/^{86}Sr$ values might indicate that the 'local' $^{87}Sr/^{86}Sr$ range was not very reliable because human dentine and faunal bone were the only references available for the sites at the Middle Volga or that the 'local' $^{87}Sr/^{86}Sr$ range based on dentine or bone was too limited, making more outliers than there should be. The variety of reference samples used allows a reliable 'local' $^{87}Sr/^{86}Sr$ range to be calculated for Boyanovo and Kirovograd and the data from these sites could indicate a large

Table 4.13 | Numbers and percentages of outlier tooth enamel samples and outlier individuals (in brackets) according to $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values. $\delta^{18}O_{water}$ was calculated using Longinelli, 1984.

site	n samples (individuals)	n outliers $^{87}Sr/^{86}Sr$	% outliers $^{87}Sr/^{86}Sr$ (samples)	n outliers $\delta^{18}O_w$ (wide frame)	% outliers $\delta^{18}O_w$ (wide frame)	n outliers $^{87}Sr/^{86}Sr$ + $\delta^{18}O_w$	n outliers $^{87}Sr/^{86}Sr$ + $\delta^{18}O_w$
Eneolithic and Bronze Age							
Benkovski	11 (9)	2 (1)	18%	–	–	–	–
Boyanovo	7 (5)	4 (2)	57%	1 (1)	14%	–	–
Ovchartsi	9 (5)	5 (3)	55%	–	–	–	–
Smyadovo	10 (8)	5 (4)	50%	8 (7)	89%	4 (4)	40%
Sárrétudvari-Őrhalom	12 (8)	6 (5)	50%	5 (4)	42%	5 (4)	42%
Kétegyháza-Kétegyházi	4 (4)	1 (1)	25%	1? (1?)	25%?	–	–
Kirovograd	14 (8)	11 (7)	79%	1 (1)	7%	1 (1)	7%
Peshtchanka	14 (7)	2/6? (1/3?)	14% ?	3 (2)	21%	2 (1)	14%
Shakhta Stepnaya	7 (4)	–	–	–	–	–	–
Vinogradnoe	25 (16)	–	–	3 (3)	12%	–	–
Nevskoe	5 (5)	0(/5)?	0(/100)%	1 (1)	20%	1 (1)	20%
Kalinovka I	3 (3)	2 (2)	67%	–	–	–	–
Nikolaevka III	9 (8)	9/8 (8)	89–100%	–	–	–	–
Podlesnyi	4 (3)	4/3 (3/2)	75–100%	2 (2)	50%	2 (2)	50%
Politotdel'skoe	3 (3)	2 (2)	66%	–	–	–	–
Olennii	7 (7)	1 (1)	14%	–	–	–	–
Sukhaya Termista II	8 (4)	2? (2?)	25% ?	1? (1?)	13% ?	–	–
Iron Age							
Alexandropol'	5 (5)	2 (2)	40%	1 (1)	20%	1 (1)	20%
Babina Mogila	2 (2)	1 (1)	50%	–	–	–	–
Drana Kokhta	2 (2)	–	–	–	–	–	–
Ordzhonikidze	6 (6)	3? (3?)	50% ?	1 (1)	17%	–	–
Zolotaya Balka	6 (6)	2 (2)	33%	1 (1)	17%	–	–
Berel' (humans)	7 (5)	4? (3?)	43% ?	2 (1)	29%	–	–
Berel' (horses)	10 (8)	4 (2)	40%	3 (2)	30%	–	–

number of people moving between different geological regions. The lower proportion of $\delta^{18}O_w$ outliers either implies that people did not move between regions of different $\delta^{18}O_w$ ranges or that the 'local' $\delta^{18}O_w$ ranges were too wide. The assumption that some of the 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ ranges were not to be relied on is supported by the small number of sites with outliers in both strontium and oxygen isotope ratios.

4.6.2.3 Identification of outliers on an intra-regional level

The mean percentage of outliers in each region highlights certain differences. Sites in the Middle Volga region (74 %) and in the Carpathian-Balkan region (41 %) have highest proportions of $^{87}Sr/^{86}Sr$ outliers, while the sites dating to the Scythian period (40 %) have slightly lower and the North Pontic samples dating to the Eneolithic and Bronze Age (19 %) have much lower $^{87}Sr/^{86}Sr$ outlier averages. A similar but narrower picture emerges when the regional means of $\delta^{18}O_w$ outliers are considered. The Carpathian-Balkan sites have an average $\delta^{18}O_w$ outlier proportion of 27 %, and the Volga samples of 8 %, whereas the North Pontic sites range about 11 %. The Iron Age sample sites show outlier averages of 11 % in the North Pontic and 29 % in Berel'. Regions with more than 10 % of outliers in both $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ occur only in the Carpathian-Balkan (14 %) and the Middle Volga regions (13 %), whereas the average outlier numbers in the North Pontic is 8 %. The Iron Age sites of the Scythian period have mean outlier values of 4 % in the North Pontic and 0 % in Berel' for both $^{87}Sr/^{86}Sr$ and $\delta^{18}O$.

4.6.2.4 Identification of outliers on an inter-regional level

The combined $^{87}Sr/^{86}Sr$ ratios of the reference samples, excluding dentine, and the $\delta^{18}O_w$ mean in the tooth enamel samples are shown in Figure 4.103. This shows that specific regions of the study area can be distinguished according to their $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ ratios, even though the geology and climate are not particularly different. The picture is marginally distorted since not all sample sites produced reference material. Nevertheless, it can be seen that the least depleted and least radiogenic values are from Bulgaria while the most depleted and radiogenic value is from Berel'. The Ukrainian samples lie between these extremes. The Hungarian references are similar to the Ukrainian material as regards the $^{87}Sr/^{86}Sr$ but have less depleted $\delta^{18}O_w$ values. They differ from the Bulgarian samples in having more radiogenic $^{87}Sr/^{86}Sr$ ratios. The references from the two South Russian sites have oxygen values comparable to Ukraine, but have less radiogenic strontium values. The reference samples from the Volga region are set slightly apart from this trend in that the strontium ratios are similar to the South Russian references but the oxygen ratios are significantly more depleted.

Figure 4.104 shows the distribution of the $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ ratios of the sampled tooth enamel. As with the reference material, the individual regions can be distinguished through their varying $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ values. While the samples from the Carpathian-Balkan region cluster between 0.708 and 0.7095 in $^{87}Sr/^{86}Sr$ and between ca. –10 ‰ and –6 ‰ in $\delta^{18}O_w$, the samples from central Ukraine in the North Pontic region are slightly more radiogenic in $^{87}Sr/^{86}Sr$ and marginally more depleted in $\delta^{18}O$, even though they overlap to some degree. The results from Eastern Ukraine and the steppes in southern Russia sit ambiguously between the above mentioned regions and are hard to separate isotopically. The results from the Volga region are distinctly more depleted in $\delta^{18}O$ with $\delta^{18}O_w$

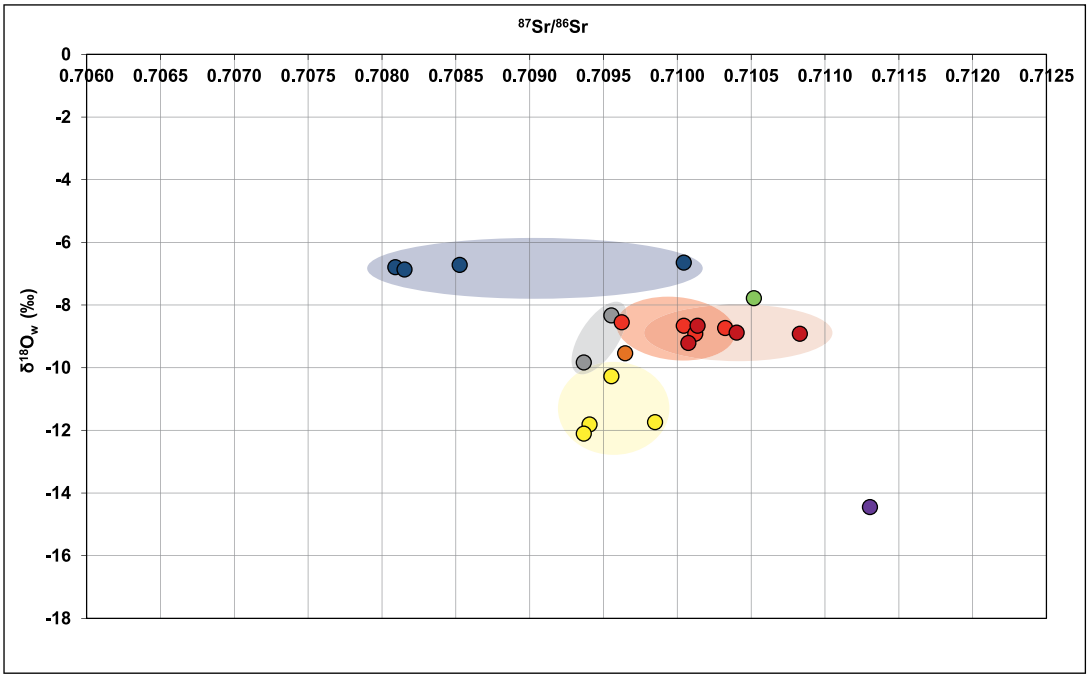


Fig. 4.103 | Distribution of $^{87}Sr/^{86}Sr$ in the reference material and $\delta^{18}O_{water}$ mean in the tooth enamel samples: Eneolithic and Bronze Age: Bulgaria (blue), Hungary (green), Central Ukraine (dark red), Eastern Ukraine (orange), South Russia (grey), Volga region (yellow). Iron Age: North Pontic (light red), Berel' (purple). $\delta^{18}O_{water}$ was calculated using Longinelli, 1984.

values primarily between –12 ‰ and –10 ‰, though they overlap with the Bulgarian samples in the $^{87}Sr/^{86}Sr$ values to some degree. This leads to the conclusion that it is to some extent possible to detect 'mobile individuals' in the study area inter-regionally based on locally and regionally varying $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ ranges. With larger sample sizes, i.e. a statistically significant sample size per site, an extended and evenly distributed choice of sample sites and an enlarged set of representative baseline samples, it might be possible to identify the origin of the first generation Yamnaya migrants in the West Pontic region or the movement ranges of the human individuals belonging to the Poltavka culture in the Volga region. On the basis of this restricted data set, however, it is only possible to make conjectures.

4.6.3 Reconstruction of economic systems

4.6.3.1 Mobility variants

The reconstruction of mobility ranges is extremely difficult in prehistoric societies that are thought to have subsisted on semi-mobile or even mobile animal husbandry to a major degree. In the present study, the reconstruction of an economic model is hampered by the lack of information about potential camp or permanent settlement sites.

Figure 4.105 shows the application of the four variants of mobility developed by W. Wendrich and H. Barnard (Wendrich/Barnard, 2008, 5–6, fig. 1.2). These variants were already discussed in Chapter 4.2.2.2 and shall be illustrated here using the example of Kirovograd. In the first variant the

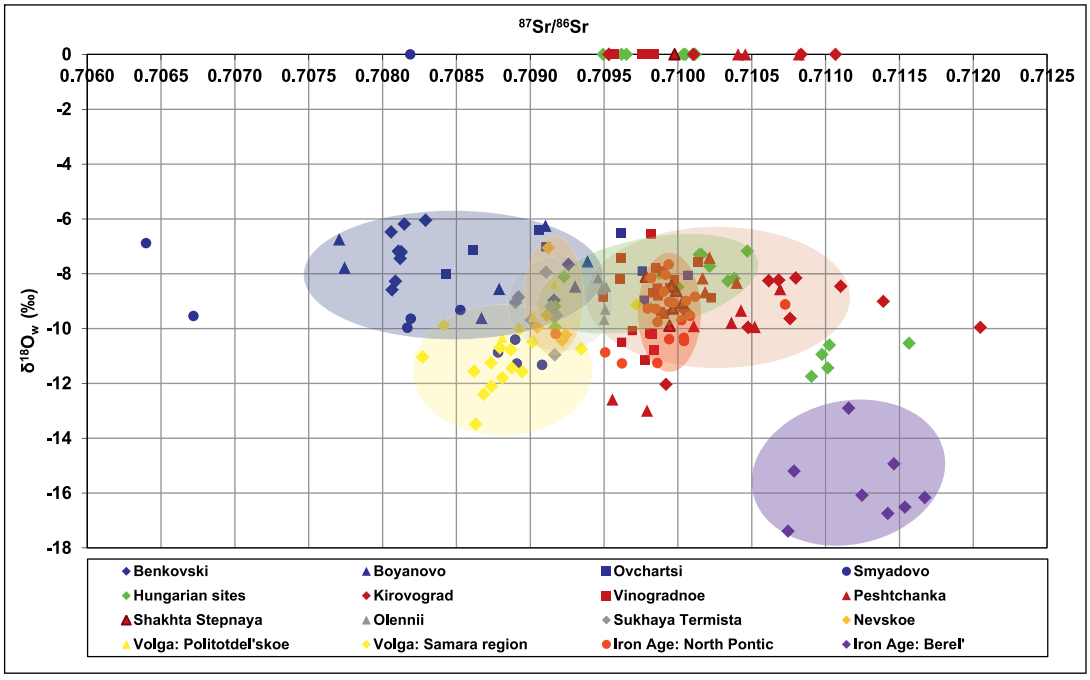


Fig. 4.104 | $^{87}Sr/^{86}Sr$ and $\delta^{18}O_{water}$ values of all human tooth enamel samples with main clusters outlined in similar colours according to region: Eneolithic and Bronze Age: Bulgaria (blue), Hungary (green), Central Ukraine (dark red), Eastern Ukraine (orange), South Russia (grey), Volga region (yellow). Iron Age: North Pontic (light red), Berel' (humans only, purple). $\delta^{18}O_{water}$ was calculated using Longinelli, 1984.

entire community is involved in movements following a fixed pattern. Due to the large geological variation in the region around Kirovograd, this would probably imply stays on varying geology, resulting in a mixed $^{87}Sr/^{86}Sr$ signal between 0.709 (Cenozoic) and above 0.712 (Proterozoic) (cf. Voerkelius et al., 2010, fig. 1). In the same area, it would be possible for communities to follow the same seasonal cycle but move only between similar geologies. This would be represented by $^{87}Sr/^{86}Sr$ values from 0.709 to 0.711 (Cenozoic only) or above 0.712 (Proterozoic only). In the case of the first scenario (a), $^{87}Sr/^{86}Sr$ signatures would be expected to differ within the community due to varying mineralisation periods of the teeth and varying points of birth and death resulting in variations of the mixed signal. The second scenario (b) also implies that the complete group is in movement. People move from one resource to the next according to no distinct pattern. Searching for new pastures, one might expect communities to move along rivers but due to the fact that kurgans are found in the open steppe as well, it can be assumed that people would also utilise areas away from direct water supplies such as rivers. For Kalmykia, however, it is assumed that the seasonal cycles of herders were largely confined to river valleys, while the exploitation of wider steppe grassland areas off the river valleys is assumed for the subsequent Catacomb culture times only (Shishlina, 2003, 360–363; Kohl, 2007, 159). The same effect occurs as in the first variant, where several input sources can result in similar Sr ratios. Mixed $^{87}Sr/^{86}Sr$ values would be expected whether the movement happened across small or large distances. A mixed signal can be defined by two known end-members. In the wide-ranging geological homogeneity of the steppes, however, this is rather difficult as mixed signals would probably be the same no matter what distance is covered. The third type of mobility (c), where several parts of the community exploit various resources would probably result in large intra-site variations due to stays in different geological regions. A significant site-internal

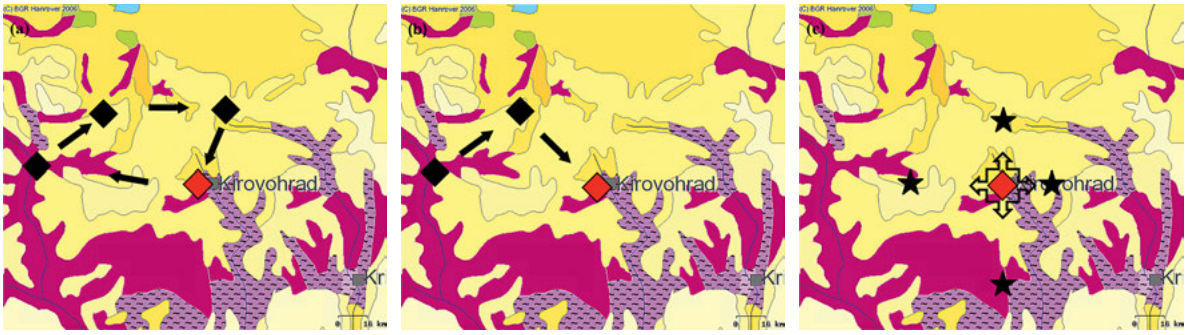


Fig. 4.105 | An example of the application of mobility types as defined by Wendrich and Barnard at the site of Kirovograd (after Wendrich/Barnard, 2008, fig. 1.2). The kurgan sites are shown as red diamonds, possible temporary residences as black diamonds. Underlaying geological map: Asch, 2005.

variation would also be expected for the second mobility variant, while the first one with its fixed and repeated movement cycle would probably result in similar ratios. The distinction of these mobility types is additionally complicated by the fact that the sampled individuals were not part of one community but belonged to different cultural periods, for Kirovograd these are the Yamnaya and Developed Catacomb cultures, and the high probability of mixed signals due to small-scale geological variations.

4.6.3.2 Elements of uncertainty

The Eneolithic steppe communities, though heterogeneous in their economies, can generally be classed as mobile stockbreeders with limited interest in crop cultivation (Anthony, 2007, 270–271), and it is assumed that the shift from a relatively settled lifestyle to a predominantly pastoralist one happened in the Early Bronze Age (Frachetti, 2008a, 20, 44). Although recent research sees the Early Bronze Age communities not as 'exclusive' herders, evidence of agricultural activities remain infrequent and scarce in the archaeological evidence (Bunyatyan, 2003, 276; Kohl, 2007, 144; but cf. also Otchir-Gorieva, 2002, 122, 126). One would expect the introduction of wheeled transport to lead to greater mobility and increased mobility ranges (Anthony, 2007, 111; Kohl, 2007, 144) and consequently to a greater number of possible temporary settlement sites. In contrast, the wagon burials sampled in the present study resulted in $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values that do not differ in their visible 'mobility levels' from the other burials (cf. Chapter 4.6.4.2).

Although it is commonly assumed (e.g. Bunyatyan, 2003; Shishlina, 2004; 2008; Shishlina et al., 2008) that the Early Bronze Age communities of the North Pontic steppe had base camps in the river valleys and stayed in the steppes only temporarily, mainly seasonally, there is no information about the range over which people moved. While modern pastoralists in Central Asia follow a vertical transhumant mobility pattern consisting of summer pastures in the mountains and winter pastures in the lowlands with annual ranges of less than 50 kilometres (Shahrani, 1979, 166; Frachetti, 2008a, 127), horizontal movement of pastoralists can result in annual ranges of several dozen to several hundred kilometres (Bendrey, in press).

Again using the site of Kirovograd as an example (Fig. 4.106a), it can be shown that there may not be any difference in the stable isotope signal of the individuals, whether the radius of movement is small or large. The restricted range of $\delta^{18}O$ values, however, would seem to indicate relatively small movement

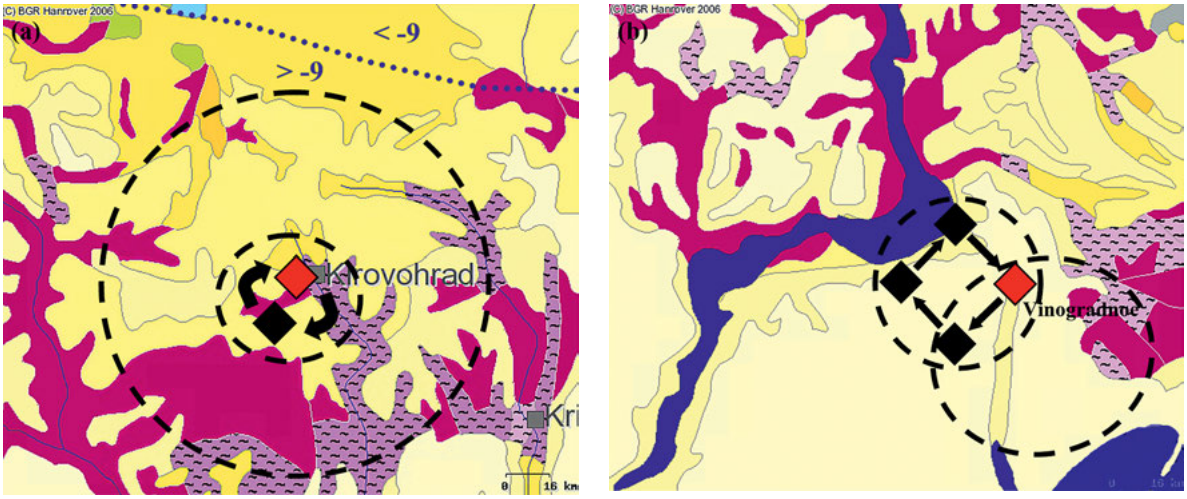


Fig. 4.106 | Model of mobility ranges for Kirovograd (a) and Vinogradnoe (b). The kurgan sites are shown as red diamonds, possible temporary residences as black diamonds. Dashed circles show potential movement ranges. Underlaying geological map: Asch, 2005.

ranges. The possibility that people led a settled lifestyle in one place and derived food from different economic zones or indeed lived in several settlements cannot be excluded. At Vinogradnoe (Fig. 4.106b) however, different movement radii could result in diverse $^{87}Sr/^{86}Sr$ values. The restricted distribution of $^{87}Sr/^{86}Sr$ values from this site suggests that movement cycles were restricted to the Cenozoic areas. This does not exclude wide movement cycles because the geology to the southwest of the study site is homogenous across a very large area. The relatively wide spread in $\delta^{18}O$ values implies the presence of some form of mobility in preference to a settled lifestyle.

The number and species of animals that are pastured will have an impact on mobility ranges and the duration of stays. For a number of sites in the western steppes between eastern Ukraine and western Kazakhstan (n = 21), R. Bendrey found an average of 70 % cattle, 20 % sheep or goat and 10 % horse bones (Bendrey, 2011, 8 fig. 3). According to the author, there is a general trend from areas where cattle comprise more than 50 % of domestic fauna to the west and those where more than 50 % are sheep or goat to the east. This corresponds with modern data, which shows a decrease in precipitation from west to east (Bendrey, 2011, 10). Sheep overgraze their pastures much faster than other domesticated animals leading to shorter durations of residence stays (Shishlina et al., 2008, 245). This leads to the assumption that herders in the east of the West Eurasian steppes were forced to move more frequently than those in the west. When comparing the site-internal variability in $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ of the North Pontic individuals to those of Southern Russia and the Volga region, a higher range of mobility is indicated in the Volga region, possibly implying shorter movement cycles and/or wider mobility ranges. It should be borne in mind, however, that disparities in $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ could also stem from other variations such as differences in chronology.

Ethnographic studies of pastoralists in the northwest Caspian region in the last century show an annual cycle of movement with winter camps being occupied for several months, while in spring and summer occupation periods were much shorter, sometimes only a few days (Shishlina et al., 2008, 247). The mobility patterns of these recent Kalmyk pastoralists compare well with the Late Bronze Age and Early Iron Age sites in the same region. If a similar model were applied to the North Pontic region, a wider range of $^{87}Sr/^{86}Sr$ values would be expected because of the influence of the very old Proterozoic

geology in the river valleys compared to the younger rocks underlying temporary settlement sites for the rest of the year.

With so few known settlement sites, it is difficult to distinguish the movement radii of groups based predominantly on burial sites. The distribution of archaeological cultures (cf. Chapter 2.1) can, however, give an indication of directions of movement or movement ranges. The classification of the Eneolithic steppe cultures is heavily debated and their distributions do not seem to have clear boundaries. The borders between the regional groups of Yamnaya and Catacomb cultures are also rather blurred.

Another issue complicating this study is that the samples derive from different chronological periods and belong to different archaeological cultures. This not only reduces sample sizes for statistical analysis but also complicates the interpretation of mobility patterns, as similar movement patterns would not necessarily be reflected by similar $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values due to time-related variations in $\delta^{18}O$, for example.

Last but not least it should be noted that the environment of the kurgans does not necessarily equate to the last place of residence. It is to be expected that communities with a certain degree of mobility did not live in the immediate environs of the point of death. It is also possible that the dead were brought to their final resting place from further afield, perhaps because of the significance of a particular kurgan for certain people. The discrepancy between calculated 'local' $^{87}Sr/^{86}Sr$ ranges and the majority of the tooth enamel results at sites such as Nevskoe and Nikolaevka might be indicators that the communities buried in the mounds lived further away and does not necessarily imply a 'real' foreign origin for all those individuals. It should be noted, however, that at both sites dentine was analysed to establish the 'local' $^{87}Sr/^{86}Sr$ range, so there might be other reasons for the disparity. Other sites like Benkovski and Vinogradnoe conform well to the 'local' signatures and imply that burial mounds were close to areas of residence.

4.6.4 Detection of a possible increase of mobility due to the emergence of draught animals, wagons and climatic changes using $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses

4.6.4.1 Site variability

There is evidence for a rapid adoption of cattle and sheep based herding economies in the western and eastern Eurasian steppes from the middle of the 3rd millennium BC (Frachetti/Benecke, 2009, 1024). 500 years later, around 3000 BC, draught transport and wagons are assumed to have come into use in association with mobile pastoralism in the Pontic-Caspian steppes. Furthermore, climate modelling shows that there was a change in climate at 5200 BP (Körper et al., in prep.), which roughly corresponds to this shift in the economic system (cf. Weninger et al., 2009, esp. 34–50).

The comparison of standard deviations offers the possibility of testing for the existence of a potential shift in mobility patterns using $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses. The Eneolithic samples date to the time before the presumed introduction of specialised herding around 3000 BC and the climate change around 5200 BP, whereas the Early Bronze Age samples are later than the supposed shift.

Appendix B Table 3 shows the site-internal mean $^{87}Sr/^{86}Sr$ standard deviations according to cultural periods and Figure 4.107 shows the $^{87}Sr/^{86}Sr$ ranges separated into regions. The mean standard deviations of the chronological periods are relatively large for the Eneolithic and the Early Bronze Age in Bulgaria and Hungary, while there are smaller mean standard deviations for the Yamnaya period in Ukraine

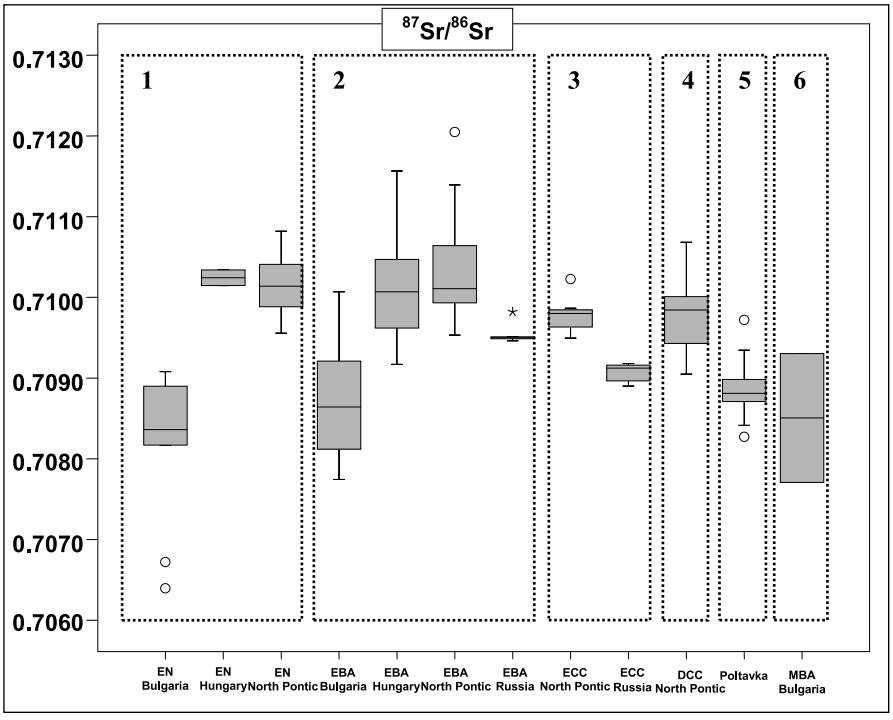


Fig. 4.107 | Box plots of $^{87}Sr/^{86}Sr$ data separated according to chronological periods and regions: 1: Eneolithic, 2: Early Bronze Age/Yamnaya, 3: Early Catacomb, 4: Developed Catacomb, 5: Poltavka, 6: Middle Bronze Age (Bulgaria).

and Russia, the Early Catacomb culture and the Developed Catacomb culture. The individuals belonging to the Poltavka culture conform to the samples from the Yamnaya, Early and Developed Catacomb cultures. The two Bulgarian samples from the Middle Bronze Age period vary by ± 0.0011. The correlation of standard deviations with sample sizes was tested using Pearson's Correlation test and resulted in no correlation ($r = 0.21$). The large $^{87}Sr/^{86}Sr$ standard deviations of the Eneolithic samples in general and the Early Bronze Age samples from Bulgaria and Hungary contrast with the smaller standard deviations of the samples in Ukraine and Russia dating to the Early Bronze Age. The largest standard deviations are seen in the Early Bronze Age samples from the Carpathian-Balkan region and the (Eneolithic and) Yamnaya samples from the North Pontic. The smallest $^{87}Sr/^{86}Sr$ standard deviations are seen in individuals from the Early Catacomb culture. This leads to the suggestion that people of this period may have practiced limited mobility, which would match the archaeological record of restricted cultural interaction and more limited distribution during the period of the Early Catacomb culture. Figures are too small and samples from one chronological period often correlate with particular sites, so there might be other explanations for these variations. Conversely, the ranges of $^{87}Sr/^{86}Sr$ values at the sites is largest (> 0.002) for the Yamnaya and Early Catacomb culture individuals at Vinogradnoe and the Poltavka samples in the Samara region.

On the basis of the $^{87}Sr/^{86}Sr$ results it can be concluded that the shift to another economic system and/or climate change may have been associated with an increased mobility between the Eneolithic and the Yamnaya period with another decrease in mobility in the subsequent Catacomb culture. It is very probable, however, that differences are site-related.

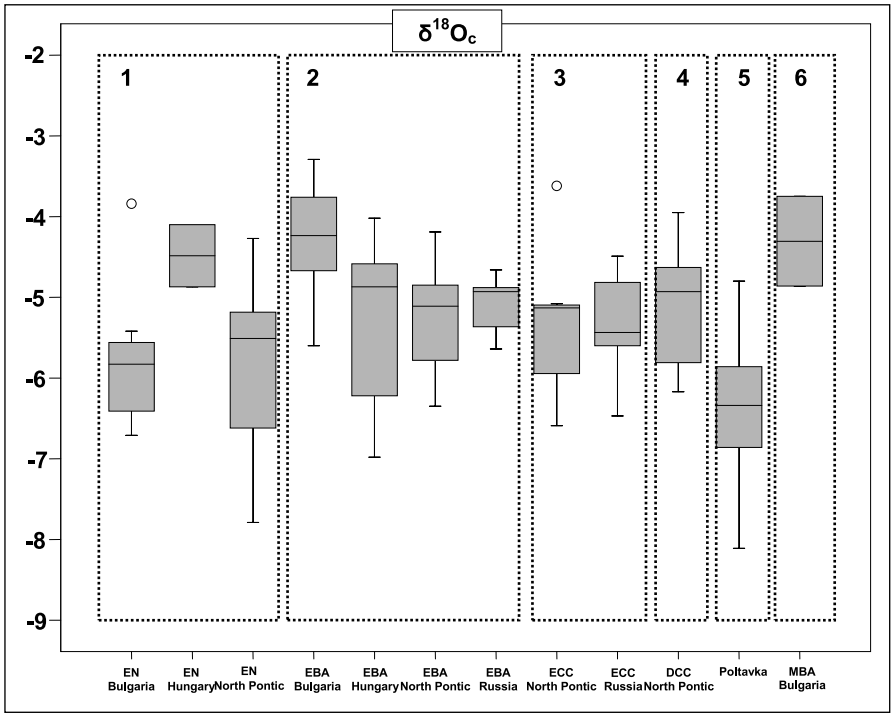


Fig. 4.108 | Box plots of $\delta^{18}O_{carbonate}$ values separated according to chronological periods and regions: 1: Eneolithic, 2: Early Bronze Age/Yamnaya, 3: Early Catacomb, 4: Developed Catacomb, 5: Poltavka, 6: Middle Bronze Age (Bulgaria).

Appendix C Table 6 shows the site-internal mean $\delta^{18}O_{carbonate}$ standard deviations according to cultural periods. The Eneolithic $\delta^{18}O_c$ standard deviations have a mean of 0.85. The Early and Middle Bronze Age individuals of the Carpathian-Balkan region show similar $\delta^{18}O_c$ mean standard deviations of 0.75 and 0.78. In Ukraine and Russia, the $\delta^{18}O_c$ mean standard deviations of the Yamnaya individuals are lower than those of the Early Catacomb culture and the Developed Catacomb culture. The sites of the Poltavka culture show a $\delta^{18}O_c$ mean standard deviation of 0.78. There is no correlation between the standard deviations and the sample sizes per site according to a Pearson's Correlation test ($r = 0.11$). The $\delta^{18}O_c$ ranges separated into regions (Fig. 4.108) show no major differences between the chronological time periods except for the transition from the Eneolithic to Early Bronze Age in the Carpathian-Balkan Pontic region (cf. Chapter 4.4.4.6; statistical comparison of the mean values). Despite the possible relationship to the geographic location, these results point to a shift in the strontium and oxygen isotope ratios between these two periods. This cannot be confirmed by the North Pontic sites.

In summary, there is no obvious chronological tendency to an increase or decrease of site-internal $\delta^{18}O$ mean standard deviations. The Eneolithic and the Early Catacomb culture samples show the largest deviations. On the basis of this data set, the $\delta^{18}O$ mean standard deviations in Bulgaria and Hungary are relatively large for all sampled periods, whereas there is no significant variation between the Ukrainian and Russian individuals across different chronological periods. In general, the results from the Eneolithic period are more depleted in $\delta^{18}O$ than those dating to the Early Bronze Age from the same site. This is true for the samples from Bulgaria and the North Pontic region but the reverse is the case for the

Hungarian samples. This could either be site-dependant or due to chronological differences and suggests a climatic change in these regions taking place between the Eneolithic and the Early Bronze Age, which would match the known climatic change occurring around 5200 BP. However, the skeleton dating to the Early Bronze Age at the Smyadovo cemetery disagrees with this interpretation. Furthermore, the results from Hungary do not completely agree with this, although it should be mentioned that only one skeleton from the Eneolithic was sampled.

4.6.4.2 Exceptional burials

To answer research questions concerning an increase in mobility associated with the spread of innovations it is essential to select the 'right' samples.[3] In this case, this would mean burials that contain noticeable features or grave goods. Objects with foreign origins or uncommon burial traditions may imply a 'non-local' origin of the individual buried with them. Furthermore, it is certainly inevitable that studies generally focus on the first generation of migrants.

Where wheeled transport is concerned, these would be graves containing complete wagons or parts of wagons, such as wheels. Here, the question arises: 'Do wagon burials in themselves imply increased mobility?' Humans from five graves that contained wagon parts or wagons were selected for analysis Table 4.14. Three of these burials were assigned to the Yamnaya culture, one to the Novotitarovskaya culture and one to the Early Catacomb culture.

Very early wagons or parts of wagons dating to the Early Bronze Age Yamnaya and Catacomb culture groups are known from the East European steppes. More than 250 finds of burials with wheeled wagons are known from burial mounds in the West Eurasian steppes (Kohl, 2002, 162 citing Ген, 2000, 176–177). The Yamnaya have the highest numbers of wagon finds, specifically the Novotitarovskaya culture in the Kuban region and the Early Catacomb culture, while the number of wagon burials decreases in the following Developed Catacomb culture. The scarcity of these burials combined with the presence of additional grave goods and the design of the burial chambers suggests, at least in the North Pontic, a higher status of the individuals buried in this manner (Kaiser, 2007, 145). In most cases, the individuals in these burials were male. In the Novotitarovskaya culture a quarter of all adult burials included wagons (Kaiser, 2007, 142–143 citing Ген, 1991, 66). Thus the question arises as to whether the new appearance of wagons in graves is associated with an actual use of wagons and hence an increase in mobility. It is important to note that the Early Bronze Age wagons were heavy carts that were connected to a mobile form of a pastoral economy and did not resemble the light chariots connected to warfare activities of later periods (Kohl, 2002, 162). Although an evaluation of the wagon burials remains difficult due to small sample sizes, some conclusions can be drawn. It is remarkable that the first and second molars of the two individuals from Kirovograd are the only samples that delivered results lying within the 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ ranges. These results could be seen as indicating lower mobility providing the reference material used to establish the 'local' $^{87}Sr/^{86}Sr$ range was reliable. The result for the third molar of burial 20, however, lay below the 'local' $^{87}Sr/^{86}Sr$ range. A $\delta^{18}O$ value was not obtained from this tooth. All individuals from Vinogradnoe, including the sampled individuals from the two wagon burials, lie within the 'local' $^{87}Sr/^{86}Sr$ range but not all samples fit comfort-

3 Sample acquisition was not subject to the PhD candidate.

Table 4.14 | $^{87}Sr/^{86}Sr$ and $\delta^{18}O_{carbonate}$ and $\delta^{18}O_{water}$ data from the sampled burials associated with wagon parts. $\delta^{18}O_{water}$ was calculated using Longinelli, 1984.

site	burial	cultural affinity	tooth	$^{87}Sr/^{86}Sr$	$\delta^{18}O_{carbonate}$ (‰ vs. V-PDB)	$\delta^{18}O_{water}$ (‰) (Longinelli)
Kirovograd, Ukraine	5	Yamnaya	M1	0.71011	–	–
			M2	0.71005	–5.42	–9.34
	20	Yamnaya	M2	0.71048	–5.82	–9.96
			M3	0.70953	–	–
Vinogradnoe, Ukraine	kurgan 3 burial 25	Yamnaya	M2	0.70995	–4.89	–8.52
			M3	0.70984	–6.35	–10.77
	kurgan 24 burial 34	Early Catacomb	skeleton 1 M3	0.70982	–5.99	–10.22
			skeleton 2 M3	0.70969	–5.90	–10.08
Olennii, Russia	kurgan 2 burial 25b	Novotitarovskaya	m2	0.70982	–5.33	–9.19

ably within the 'local' $\delta^{18}O_w$ range. The outlier $\delta^{18}O_w$ values of these individuals cluster relatively tightly at the lower margin of the 'local' range. This might infer periodic residence further to the north at a place with similar geology. The differences in values are small but as these individuals did not belong to the same culture, it would be impossible that they were 'travel companions'. Remarkably, the wagon burial from Olennii is the only grave from that site that differs in its $^{87}Sr/^{86}Sr$ value though this result is difficult to interpret because the second premolar sampled had probably not totally mineralised at the time of death and might therefore have been isotopically altered in the burial environment.

In conclusion, the few wagon burials do not differ significantly from the rest of the sampled burials in their stable isotope results, which implies that these individuals were not appreciably more mobile than the wider population.

Further indicators for increased mobility include offerings of draught and riding animals like cattle and horses, but these animals are not common additions to graves in these cultural traditions. In many cases, animal bones in burial contexts were not specified in excavation reports. Cattle and/or horse bones were included in the following burials: Sárrétudvari-Őrhalom, Hungary, burials 10 and 11 (in the grave filling), Kirovograd, Ukraine, burial 5 (horse tooth) and Nevskoe, Russia, kurgan 4 burial 3 (bovine astragal). Skeletal remains of sheep derive from Kétegyháza-Kétegyházi, Hungary, kurgan 3 burial 7 (astragaloi), Kirovograd, Ukraine, burial 16, Vinogradnoe, Ukraine, kurgan 24 burial 8, Olennii, Russia, kurgan 2 burial 35b (sheep/goat skull), Kalinovka I, Russia, kurgan 1 burial 4, and Nikolaevka III, Russia, kurgan 2 burial 1. However, there are no remains of complete animals. This differs in the Scythian period, where horses were commonly part of the burial equipment and most cases where primary burials were selected for analysis included horse sacrifices. Two horses with equipment were deposited in the central burial at Drana Kokhta, Ukraine. Horses were also found in most of the burials in Berel', Kazakhstan. Horses are generally common in burials of the Scythian elite so they do not necessarily imply an increased degree of mobility of this distinct human buried. However, the majority of individuals in graves that included remains of herding, draught or riding animals did not lie outside the predicted 'local' isotope ranges.

Table 4.15 | Mean $^{87}Sr/^{86}Sr$, median $^{87}Sr/^{86}Sr$, standard deviations, ranges and minimum and maximum values and median $\delta^{18}O_{carbonate}$, mean $\delta^{18}O_{carbonate}$, standard deviations, minimum and maximum values and ranges for the Iron Age sites sampled according to regions.

site	**n (samples)**	**median $^{87}Sr/^{86}Sr$**	**mean $^{87}Sr/^{86}Sr$**	**± 1σ**	**min.**	**max.**	**range**
North Pontic	21	0.70994	0.70991	0.0003	0.70994	0.70998	0.0004
Berel'	8	0.71134	0.71125	0.0003	0.71075	0.71167	0.0009
site	**n (samples)**	**median $\delta^{18}O_c$ (‰ vs. V-PDB)**	**mean $\delta^{18}O_c$ (‰ vs. V-PDB)**	**± 1σ**	**min. (‰ vs. V-PDB)**	**max. (‰ vs. V-PDB)**	**range**
North Pontic	21	–5.39	–5.54	0.66	–6.67	–4.34	2.33
Berel'	8	–9.56	–9.81	0.90	–10.63	–7.73	2.90

In further research, the graves of metallurgists might be interesting to sample since they may have been itinerate craftsmen, who lead more mobile lives.

4.6.5 Mobility in the Iron Age Scythian period

4.6.5.1 Human mobility

It is assumed that fully-fledged pastoralism developed in the 1st millennium BC and was associated with the wide spread of common cultural elements across wide parts of the steppe and the use of the horse (Jacobson-Tepfer, 2008, 201, 225; Parzinger, 2009, 19; Bendrey et al., in press). Archaeological evidence such as horse burials and exclusive foreign grave goods and historical sources lead to the assumption that the Scythians, and other steppe cultures affiliated to them, led a highly mobile way of life. The comparison of the mean standard deviations of $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ of the samples from sites dating to the Iron Age Scythian period with those of the preceding periods shows no significant differences however (Table 4.15).

The $^{87}Sr/^{86}Sr$ mean standard deviation for both the North Pontic individuals and those from Berel' is 0.0003, and the $\delta^{18}O_{carbonate}$ mean standard deviation is 0.66 for the North Pontic region and 0.9 for Berel'. The mean $\delta^{18}O_c$ standard deviation for the North Pontic region is similar to those of the Eneolithic and Bronze Age in the same region, while that for Berel' is one of the highest in the entire data set (Appendix C Table 6). There are no differences between the North Pontic samples of the Iron Age and (summarized) preceding periods [$t = 1.19$, $p = 0.238$ (in $\delta^{18}O$) and $t = 1.65$, $p = 0.104$ (in $^{87}Sr/^{86}Sr$) performing a t-test]. The shift in $^{87}Sr/^{86}Sr$ ranges between higher variability in the Eneolithic and Yamnaya period and lower variability in the Early and Developed Catacomb culture continued into the Scythian period (Fig. 4.109). The $\delta^{18}O_c$ results show no significant differences in the ranges of the different chronological periods in the North Pontic (Fig. 4.110). An analysis of the North Pontic results suggests that a possible shift in the degree of mobility between the Scythian period and the Eneolithic, Early and Middle Bronze Age periods cannot be detected by $^{87}Sr/^{86}Sr$ or $\delta^{18}O$ analyses. In addition, the results of the $\delta^{18}O$ analysis suggest that mobility increased in the Scythian period in the Altai region and that vertical mobility is easier to detect than horizontal mobility in this study area.

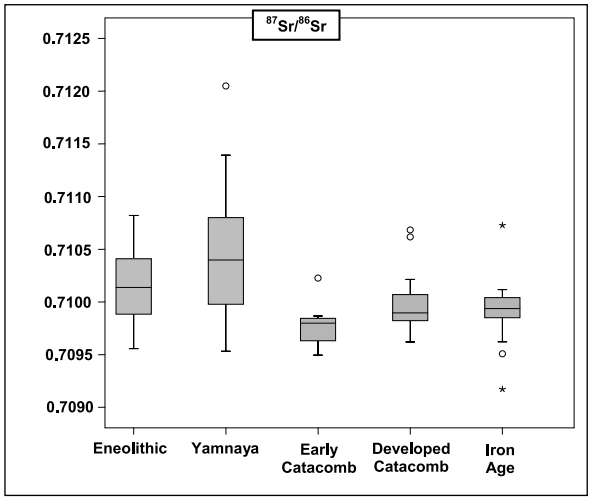


Fig. 4.109 | $^{87}Sr/^{86}Sr$ ranges of the North Pontic samples.

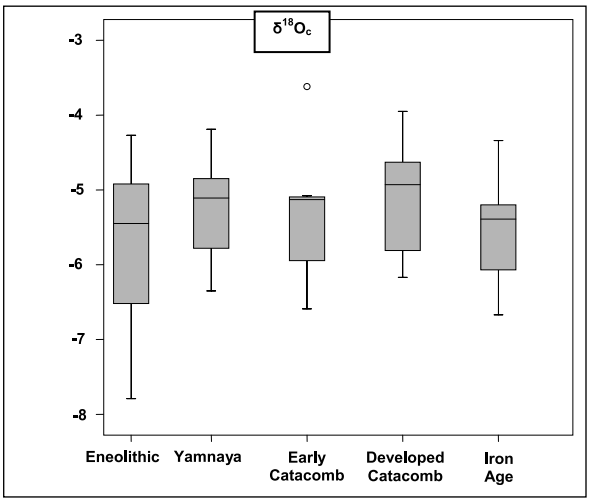


Fig. 4.110 | $\delta^{18}O_{carbonate}$ ranges of the North Pontic samples.

4.6.5.2 Evidence for faunal mobility in the Iron Age Scythian period

The domestication of the horse is one of the events that had a profound impact on human society. In the Eurasian steppes the evidence of horse bones in archaeological contexts becomes much more common from the 5th millennium on and is seen as being connected to important changes in the steppe ecodynamics at that time (Levine, 1999, 29). The first verification of horse domestication, however, is still debated (cf. Levine, 1999; 2004; Olsen, 2006) and various parts of the Eurasian steppes including sites like Dereivka, Ukraine, and Botai, Kazakhstan, are often discussed as potential sites of early domestication of the horse (cf. Levine, 1999; Hanks, 2010, 474). Using aDNA analysis, various research groups have attempted to answer the question of mono- or polycentric horse domestication processes (e.g. Ludwig et al., 2009; Pruvost et al., 2011; Warmuth et al., 2011; cf. also Benecke et al., 2007, 33–37). In a recent article Outram and colleagues used different lines of evidence, metrical analysis, pathological characteristics and organic residue analysis to suggest that horse domestication took place in the Eneolithic Botai culture, Kazakhstan, by the middle of the 4th millennium BC (Outram et al., 2009).

An increase in horses across the Eurasian steppes is supposed to start around the late 3rd millennium BC (Kohl, 2007; Bendrey, 2011, 5). For the central Asian steppes a correlation between the increase in horses and opportunistic hunter foragers in the Bronze Age was suggested by the zooarchaeological evidence from the pastoralist settlement of Begash, Kazakhstan (Frachetti/Benecke, 2009, 1036). By the Iron Age, horses were involved in both the pastoral economy and mounted warfare and gained additional significance as political and military symbols (Frachetti/Benecke, 2009, 1035; Hanks, 2010, 476). Horses must surely have played a major role in the Scythian period of the 1st millennium BC and were a frequent burial offering in elite burials of many Scythian cultural groups. The archaeological and historic evidence leads to the assumption that (people and) horses during the Scythian period were highly mobile. Changes in pastures, or movements associated with trade or warfare, are reflected in the isotopic signal in animal teeth due to changes in precipitation and food sources (Higgins/MacFadden,

2004, 343) and can be revealed through stable isotope analysis. The sequential sampling of tooth enamel enables the detection of movement, mainly seasonal, over several months. Depending on the tooth selected, the isotopic signal of an entire year can be seen in the analysis of a 3 to 4 cm vertical section of a horse tooth (e.g. Hoppe et al., 2004).

In the present study, five horses from the Pazyryk cultural site of Berel' were obtained for stable isotope analysis. From each tooth, one vertical section and two horizontal sections, one at the cusp and one at the cervix, were analysed for $^{87}Sr/^{86}Sr$ and $\delta^{18}O$. There is no information on which of the horses in the kurgans and which teeth were sampled, but the archaeological evidence points to foreign origins of some the horses buried in these kurgans. The cusp and cervix sections of the horse teeth had a mean $^{87}Sr/^{86}Sr$ ratio of 0.71158 ± 0.00076 (1σ, median 0.71132), and a range of 0.002. Remarkably, some horses, those from kurgans 9 and 11, showed large differences to the human and other horse samples in their $^{87}Sr/^{86}Sr$ values. The mean $\delta^{18}O_c$ (V-PDB) value for the horizontal tooth enamel samples of the horses was –11.04 ± 0.98 ‰ (1σ, median –10.75 ‰) with a range of 3.07 ‰. This is a comparable range to that of Bendrey and colleagues (in press) for ten Iron Age horses from the Mongolian Altai (~ 3 ‰), and is significantly smaller than the intra-population ranges of modern equids in a single feral population in a temperate climate (approximately 5 ‰, Hoppe et al., 2005). Since most of the $\delta^{18}O$ values do not differ from the 'local' range for Berel' it is suggested that the horses spent some parts of their lives in a region, Sr isotopically and archaeologically distinct from the vicinity of the burial site, with similar $\delta^{18}O$ values. This region could potentially be found in other parts of the Altai Mountains with a similar altitude. The large intra-tooth variability in $\delta^{18}O$ from the horses in kurgans 18 and 23 indicate changes of residence occurring over several months or up to one year. Despite the natural occurring seasonal variations in $\delta^{18}O$, variations to this degree might indicate a change of pastures at different altitudes and slightly differing geology. Furthermore, the $^{87}Sr/^{86}Sr$ results from laser ablation on three selected teeth (cf. Chapter 4.5.2) suggest a movement between the same or similar pastures, maybe between winter and summer. Remarkably, there is a high outlier rate when looking at either $^{87}Sr/^{86}Sr$ or $\delta^{18}O$ but none of the horses is an outlier in respect of both isotopic systems. In general, the results of the horses from Berel' point to a transhumant economy comprising seasonal shifts of pastures at different altitudes, which had been adapted to the ecosystem of the Altai Mountains (cf. Samashev, 2011, 219) though movements associated with warfare, trade or exchange cannot be excluded.

4.6.6 Isotopic indicators for possible migrations from the steppe area to the west

The presence of foreign objects and changes in the material culture are indicators of cultural interaction such as trade, exchange or the migration of individuals (Knipper, 2004, 637). Migration studies have varied in their focus, with some concentrating on the identification of migrants at one study site while others compare several archaeologically linked sites or aim to identify not just the migrants but also their distinct regions of origin (cf. Knipper, 2004, 645–646). Both types of migration studies provide the best results when based on long-range and large-scale stable isotope analysis of a particular site and its environs as well as possible regions of origin. In the present study, an extensive isotopic characterisation of all sample sites and the possible regions of origin is unrealistic because of the scale of the study area and the large number of sites sampled.

One of the objectives of this study is the identification of possible migrations originating in the North Pontic towards the plains that today include Romania, Bulgaria, Serbia and Hungary. It is widely

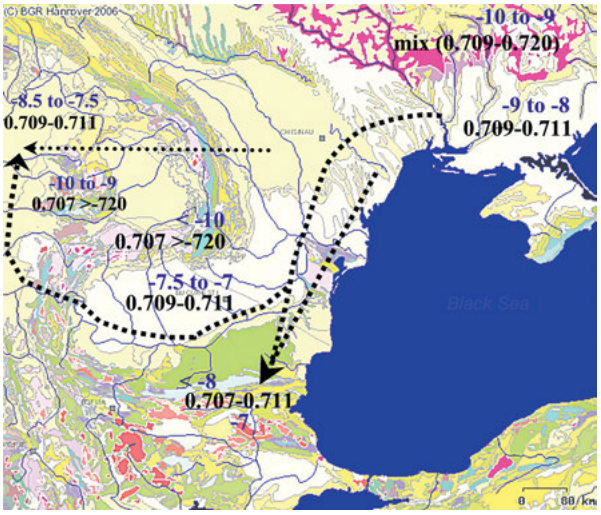


Fig. 4.111 | Potential migration routes originating in the steppes and leading to modern Bulgaria and Hungary. The map includes estimated $^{87}Sr/^{86}Sr$ and $\delta^{18}O_{water}$ (‰) values for the adjacent regions.

suggested that Eneolithic and Early Bronze Age individuals migrated west of their original distribution area in the East European steppes (see Chapter 2.1.5). According to D. W. Anthony (2007, 363–364), the westward Yamnaya migrations originated in the region between the rivers Southern Bug, Ingul and Dnieper, for which approximate $^{87}Sr/^{86}Sr$ signatures of 0.709 to 0.711 (cf. Asch, 2005) and $\delta^{18}O$ signatures of approximately –9 ‰ to –8 ‰ (cf. Bowen, 2010) would be expected. Possible migration routes from the North Pontic steppes into the Eastern Hungarian Plain and the territory of modern Bulgaria are shown in Figure 4.111. Only the first generation of migrations can be identified applying $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analysis on human tooth enamel. Pioneer migrants may take more than one generation to cross the whole distance to the ultimate destination region, which would hinder their detection through isotopic analysis. According to Anthony, the first generation of migrants would take decades to reach regions several hundred kilometres away, while succeeding generations of migrants would need significantly less time to follow them (cf. Chapter 4.2.3, see also Grupe et al., 1997, 524). The possibility that people were born anywhere between the North(west) Pontic and the Thracian and the Hungarian Plain must be taken into account. Furthermore, migration distances are not necessarily extremely long considering the presence of the Yamnaya culture also in the regions around the Lower Danube. The Bulgarian Dobrudzha, for example, can be expected to feature highly varying $^{87}Sr/^{86}Sr$ values, between 0.707 and above 0.720, due to the presence of Mesozoic, Palaeozoic and Precambrian geology. According to the OIPC (cf. Bowen, 2010) $\delta^{18}O$ values in modern precipitation range around –7.5 ‰ to –7 ‰. The same $\delta^{18}O$ values are expected for regions along the Danube in Romania but associated with $^{87}Sr/^{86}Sr$ values of approximately 0.709 to 0.711.

The Bulgarian sites gave $^{87}Sr/^{86}Sr$ values ranging from 0.7064 to 0.7101 with a mean of 0.7086 ± 0.0008 and a mean $\delta^{18}O_w$ value of –8.16 ± 1.49 ‰ (10), or –7.55 ± 0.96 ‰ excluding Smyadovo. Values range from –11.33 to –6.05 ‰. The Bulgarian samples have lower $^{87}Sr/^{86}Sr$ ratios and are less depleted in $\delta^{18}O$ on average but show a certain overlap with the North Pontic and Northwest Pontic region. The outlier values from the Bulgarian sites on the whole do not agree with either the estimated $^{87}Sr/^{86}Sr$ or $\delta^{18}O$ values for the North Pontic and Northwest Pontic regions. Either the $^{87}Sr/^{86}Sr$ values are too low when associated with $\delta^{18}O$ values matching the North Pontic region or the $\delta^{18}O$ values are not depleted enough when they match the North Pontic $^{87}Sr/^{86}Sr$ signature. The archaeology at the sampled burials

gives no specific indication of a North Pontic origin. Most burials at the sites of Benkovski, Boyanovo and Ovchartsi are not dated, lack grave goods and are assigned to the Yamnaya culture because of their skeleton positions and the presence of burial mounds.

On the basis of the isotope signatures and archaeological information, it is not possible to confirm or deny a North or Northwest Pontic origin. While the isotope ratios from the humans in Benkovski can be interpreted as indicating a settled community, the scattered $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values from Boyanovo and Ovchartsi indicate different places of residence and/or the burial of several communities. This might imply a more mobile lifestyle but may also include migrations. Since one of the Eneolithic skeletons from the site of Smyadovo matches the 'Bulgarian' $\delta^{18}O$ range, the variations between the Eneolithic and the Bronze Age individuals cannot satisfyingly be explained by changes in climatic conditions over time. So, if climatic factors are excluded as a possible explanation for the differences at other sites in Bulgaria, it might be suggested that all of the sampled humans from this site were immigrants. The values do not match the estimated $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ ranges for regions in the North and Northwest Pontic and the origin of all the individuals would have to have been even further east. One might think of a combination of factors to explain the depletion in $\delta^{18}O$ including colder climatic conditions and water supply from the Balkan Mountains.

The majority of the results from the Hungarian sample sites conform to the estimated regional $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ ranges. Four samples from Sárrétudvari-Őrhalom, however, show higher $^{87}Sr/^{86}Sr$ and lower $\delta^{18}O$ values. Three of these outliers (burials 4, 7 and 9) are at the upper margin of the regional $^{87}Sr/^{86}Sr$ range or slightly above that range, dependant of the width of range considered. The fourth outlier, burial 11, varies significantly. The outlier results fit better with $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ signatures from the Carpathian Mountains, where more depleted oxygen isotope values combined with low to highly radiogenic strontium isotope values can be expected. The combined evidence from $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses and archaeological information suggest that these individuals originated in mountainous regions further east or southeast, for example in Transylvania (cf. Gerling et al., 2012a; Gerling et al., 2012b). Links with the rest of the Carpathian Mountains or central Ukraine, however, cannot be excluded.

In summary, it is impossible to distinguish between a one-time migration and regular mobility on the basis of the small data set and the lack of $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ reference materials from the surrounding regions.

4.7 Conclusions Chapter 4

Chapter 4 focused on the identification of mobility patterns and possible migrations in the Pontic-Caspian steppes and adjacent areas during Eneolithic, the Early and Middle Bronze Age and the Scythian periods using $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses. First, theories on mobility and migration in archaeological research were introduced, the basic theories and methods of strontium and oxygen isotope analysis were described and results of the isotopic analyses were presented. The results were then compared to the 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ ranges deriving from the analysis of reference material in the case of $^{87}Sr/^{86}Sr$ and on the comparison to estimated $\delta^{18}O$ in precipitation. Furthermore, results of both isotopic systems were combined, compared and interpreted.

Sample selection was less than ideal and complicated by the limited availability of relevant numbers of individuals at sample sites. Sample sizes per site in respect to chronological periods, sex and age

groups were mainly too restricted to apply statistical analysis successfully. An attempt was made to establish 'local' and 'regional' $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ ranges, which were based on reference samples with varying degree of reliability. For $^{87}Sr/^{86}Sr$, a combination of sediment, plant and faunal samples, dentine and bone proved useful due to broad agreement between each other and with the environment. Dentine and bone samples mostly resulted in ranges that were too restricted but which often agreed with soil leachates. Sediment sample leachates mainly corresponded to the estimated $^{87}Sr/^{86}Sr$ values of the surrounding geology. The relatively low numbers of outlier $\delta^{18}O$ values indicate that the definition of the 'local' $\delta^{18}O$ range might be too vague since the Eastern European steppes show relatively large ranges of similar $\delta^{18}O$ signatures.

Intra-individual sampling using two teeth from selected individuals proved to be a good tool to investigate residence changes during childhood and adolescence, changes in mobility patterns and/or dietary shifts. For a number of samples, for example, a change was observed from less depleted $\delta^{18}O$ values in first molars to more depleted values in teeth forming at a later stage, probably due to a breastfeeding or weaning effect.

It was recognised that the identification of outliers is difficult on the basis of the existing data. This is also true for the transfer of the mobility models discussed in Chapter 4.1, which were exemplarily applied on the site of Kirovograd. This is due to a number of elements of uncertainty such as unknown mobility ranges and cycles in predominantly pastoral societies, unknown duration of stays and location of camps or permanent settlement sites. Furthermore, it is not known whether the environment of the burial mounds represents the residence areas of the last years of life. Site-internal outliers vary significantly from 0% to up to maybe even 100%, and an interpretation of this data is difficult due to the differences in reference sample reliability. A high percentage of outliers in respect to either $^{87}Sr/^{86}Sr$ or $\delta^{18}O$ are seen most particularly at sites in Bulgaria and Hungary and in the Russian Middle Volga region, which might be explained by higher variations in geology and the number of factors influencing $\delta^{18}O$. Outliers in respect to both isotopic systems are, however, rare. The plotting of $^{87}Sr/^{86}Sr$ or $\delta^{18}O$ values of all tooth enamel and reference samples illustrated that the different study regions can be distinguished from each other. This shows that despite the complex factors relating to $\delta^{18}O$ analysis, the combination of $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses is a useful tool to identify mobility patterns and migration.

Although no certain shifts in $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values could be detected, some potential changes could be suggested around the time when specialised stockbreeding and climatic changes occurred, around the turn of the 4th to the 3rd millennium BC. There is no clear chronological trend; although the Early (and Developed) Catacomb culture has extremely limited $^{87}Sr/^{86}Sr$ ranges. Strontium and oxygen isotope data obtained from wagon burials did not suggest a relative increased mobility compared to burials without wagons.

The Iron Age Scythian samples from the North Pontic show restricted $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ ranges. They are as limited as in the Catacomb culture and seem to be more restricted than the values of the North Pontic Eneolithic and Yamnaya individuals. This does not necessarily imply more limited ranges but might indicate the presence of one community with a similar nutrition in contrast to several communities with varying diets. The horses from the Altaian site of Berel' indicate the existence of seasonal mobility associated with transhumance and/or movements in relation to warfare activity due to large intra-tooth variations. In addition, there are differences among the horses which point to various places of origin matching the archaeological record of distinct differences in horse equipment adornment.

Migrations originating in the North Pontic steppes into regions to the west that are particularly suggested for the Yamnaya period can neither be accepted nor rejected on the evidence of $^{87}Sr/^{86}Sr$ and $\delta^{18}O$

analyses of the selected individuals in kurgan burials from Hungary and Bulgaria. Some individuals from Hungarian and Bulgarian burial mounds may have had foreign origins. Their isotopic signals might match the North Pontic region but could also match other regions. Some of the Hungarian samples suggest an association with the mountains, perhaps connected with transhumance. The isotopic patterns of the Bulgarian individuals suggest varying mobility patterns. The consistency of $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values in Benkovski suggests that a single community is represented here, with a restricted mobility range and/or similar dietary and water sources. The scattered isotope ratios of the individuals from Boyanovo and Ovchartsi on the other hand, propose the existence of one community that is more mobile or several community groups with higher degrees of mobility. This observation supports the archaeological evidence, which suggests that the individuals from Boyanovo and Ovchartsi are affiliated to the Yamnaya communities, in contrast to those in Benkovski. On the basis of this data, the representation of one single community might also be the case at sites like Nevskoe in Eastern Ukraine and Olennii in the Kuban region, while the distribution of $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values at sites like Kirovograd and Peshtchanka suggest the presence of several communities, although samples derive from different time periods at the latter two sites. It should be borne in mind that more scattered $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values and wider ranges of sampled individuals compared to the naturally occurring 'local' range do not necessarily equal increased human mobility but might only be the result of faunal mobility and of food deriving from several economic or geographic areas.

5 Case study: Faunal mobility in the context of the Globular Amphora culture

5.1 Introduction

The key research topic of *Topoi* research group A II is the spread and effect of innovations. The present study approaches the research question through the application of stable isotope analysis and focuses on human mobility in the West Eurasian steppes in prehistoric times. In addition to the isotopic investigation of horses from the Central Asian site of Berel', another pilot study of faunal mobility shall be included. This pilot study analysed cattle teeth from a western Globular Amphora culture[1] burial, with a view to assessing the potential contribution of faunal samples to understanding human movement.

5.2 Theories of faunal mobility

A detailed discussion of the research history of mobility and migration theories and models was the subject of chapter 4.2. In this section, aspects of mobility that are characteristic to animals are investigated in more detail. C. Knipper (2004, 663–664, fig. 23) classed faunal migration as wild and domestic animal movements that can either follow a regular, mostly seasonal, pattern or take place as a non-regular, one-time migration. Examples of regular mobility are the movements of wild animals and the nomadism or transhumance sometimes associated with domestic animals, while the trade of wild or domestic animals and changes of locations connected with animal breeding are forms of non-regular mobility.

Possible combinations of animal and human mobility are presented in Table 5.1. While some aspects of animal mobility are associated with human mobility, for example the movements of wild animals with hunter-gatherer societies or of domestic animals with nomadic or semi-nomadic communities, other forms of animal mobility are connected to sedentary humans, for example with sedentary hunter-gatherer communities or with semi-nomadic or semi-sedentary pastoralist groups. The economy of nomadism relies exclusively on mobile stockbreeding (Khazanov, 1984, 15–17; Scholz, 1994, 72), whereas semi-nomadism is characterised by animal husbandry in parallel with agriculture, usually periodical in nature (Hütteroth, 1959, 40–41; Knipper, 2011, 114). Transhumance is a distinct form of mobile economy, where animal husbandry and agriculture are independent and where only one segment of the group, the herdsmen, is mobile. The herder's mobility depends on periodic movements between pastures, while the majority of the community is settled and engaged in farming (Rudenko, 1969, 16–17; Khazanov, 1984, 16, 22; Knipper, 2011, 114). There are various types of transhumance such as distant-pastures husbandry, where year-round pasturing animals do not return to the settlement overnight, *Yaylag* pastoralism, where stock is moved between pastures of differing altitudes and distances, and the *Triftwirtschaft*, or pasture-economy, where animals pasture near-by and return to the settlement overnight (Khazanov, 1984, 22–23; Scholz, 1994, 72). One specific type of transhumance is alpine farming, where different altitudinal belts are seasonally used for animal husbandry and farming activities (Arbos, 1923, 567; Knipper, 2011, 115–116).

1 The 'Western Globular Amphora culture. Investigations into the differentiation in space and time and the cultural and anthropological identity' was subject to the PhD thesis of M. Woidich within the framework of the same *Topoi* research group.

Table 5.1 | Mobile and non-mobile livestock keeping (after Knipper, 2004, 667 table 10).

	humans mobile	**humans non-mobile**
domestic animals mobile	nomadism/semi-nomadism	transhumance, semi-sedentary pastoralism
domestic animals non-mobile	coexistence of different economic strategies	sedentary communities with nearby pastures or animal housing

On the other hand, the combination of human mobility with non-mobility of animals suggests parallel economic strategies within a community. Sedentary communities associated with animal housing or near-by pastures represent the most stationary form of animal husbandry and result in non-mobility of either animals or humans. Year-round local animal husbandry requires a plentiful supply of pasture and fodder (Knipper, 2004, 663, table 10; Knipper, 2011, 114–116).

5.3 Stable isotope analysis of faunal mobility

Stable isotope analyses have widely been used in zoological research to identify the origin or mobility patterns of animals, for example Koch et al. (1992) on the migratory behaviour of salmon, Hoppe et al. (1999) on the migratory behaviour of mammoths, and Britton et al. (2009) on modern caribou. Faunal migration in archaeology has only recently become a subject of research, for example Balasse et al. (2002) on sheep and sheep herders in South Africa, Schweissing and Grupe (2003b) on Roman cattle horn, Towers et al. (2010) on Early Bronze Age cattle and aurochs in Britain, and Bendrey et al. (in press) on Iron Age horses in the Altai mountains. Reconstructions of pastoral economies are the subject of a number of more recent studies, for example Evans et al. (2007), Schatz and Stephan (2008), Knipper (2011), and Stephan et al. (2012).

Tooth enamel from animals with high-crowned or hypsodont teeth such as cattle (cheek teeth) and horses (all permanent teeth) is suitable for seasonal mobility reconstruction because the teeth continue to mineralize incrementally along the growth axis of the tooth, from top to bottom. The sequential sampling of multiple horizontal slices of several teeth would therefore enable a reconstruction of the movements of an animal over a long period, showing both seasonal mobility and one-time migrations (Balasse, 2003; Knipper, 2004, 663–664, 668).

The sampling of the Globular Amphora culture cattle deposition in Zauschwitz is restricted to the three premolars and the three molars of the cattle. Discussion therefore focuses on these teeth. In general, cattle dentition includes 32 teeth. Cattle mandibulae include three incisors, one canine, three premolars and three molars on each site, while the front teeth are missing in the maxillae (Weiß et al., 2011, 38–39). Tooth mineralization starts at the morsal surface and continues in the direction of the root. Mineralization of the first molar tooth enamel in cattle starts *in utero* and is completed at the age of 2 to 3 months (Table 5.2). First molars erupt between 4 and 6 months and are in wear between 7 and 14 months of age. Second molars start mineralizing at the age of 1 month, subsequently erupt around 15 to 18 months and are in wear between 19 and 24 months of age. They mineralize until the age of 12 to 13 months. Third molars mineralize between 9 or 10 months and 23 to 24 months. They erupt at approximately 25 to 34 months of age. The crown formation of the three premolars takes place in the second year of life, starting with P2 at the end of the first year, at around 9 to 10 months of age. Tooth mineral-

Table 5.2 | Tooth enamel crown formation in cattle (after Brown et al., 1960, 15 table 4; cf. also Knipper, 2011, 134 fig. 8.4).

Tooth	Begin crown formation (in months)	Completion crown formation (in months)	Duration crown formation (in months)
P2	12–13	22–23	~ 10–11
P3	9–10	16–20	~ 7–11
P4	11–12	24–30	~ 13–19
M1	*in utero*	2–3	~ 3–4
M2	1	12–13	~ 11–12
M3	9–10	23–24	~ 13–15

ization in these teeth mainly overlaps (Brown et al., 1960, 15 table 4; Schweissing, 2004, 40; Benecke, 2003, 71 table 5).

5.4 Archaeological framework

5.4.1 Globular Amphora culture and cattle depositions

The samples for the pilot study of animal mobility are associated with the Globular Amphora culture, which dates approximately to the middle of the 4th to the second half of the 3rd millennium BC in Poland (Szmyt, 1999, 9; Szmyt, 2008, 218) and to approximately 3100 BC to 2700 BC in the Middle Elbe-Saale region (Döhle/Pape, 2006, 83). In most regions it can generally be dated to the first half of the 3rd millennium BC (Szmyt, 2003, 402) and is hence contemporaneous with the Yamnaya culture. The Globular Amphora culture occurs first in the Kuyavian region, Poland, and later spread to the west and east (Döhle/Pape, 2006, 83). Finds are distributed as far as the Rhine in the west and the Baltic and northwest Pontic region in the east. The Globular Amphora culture can be subdivided into three regional groups: the central or Polish group, the eastern group and the western group. Additionally, local variants can be characterized within these regional groups and in the peripheries there are signs of influences from other cultures (Beier, 1988, 86; Szmyt, 2003). The culture gets its name from globular shaped ceramic amphorae, which are the most frequent burial objects found together with polished flint axes, flint chisels, bone tools, especially double bone points, and occasionally amber adornment (Behrens, 1973, 121). These objects accompany single or multiple crouched burials with various regionally varying orientations. Variations of graves occur; there are ordinary burial pits, stone cist burials, graves covered by stone settings, cremation burials and burials in megalithic tombs (Wojchiechowski, 1998, 406).

The scarcity of known permanent settlements, sites characterized as seasonal camps, the occurrence of Amphora culture finds in other site contexts and the prominent significance of the cattle, visible in so-called cattle burials, suggest that the people of the Globular Amphora culture lived in small mobile communities predominantly living from stock breeding (e.g. Szmyt, 2002; Döhle/Pape, 2006, 84). Based on her analysis of the finds in the Kuyavian region in Poland, M. Szmyt proposes a model for the social organisation of the Globular Amphora culture (Szmyt, 2002, 216–219, fig. 24; Czebreszuk/Szmyt, 2011, fig. 8). According to this model (Fig. 5.1), two forms of settlement organisation can be

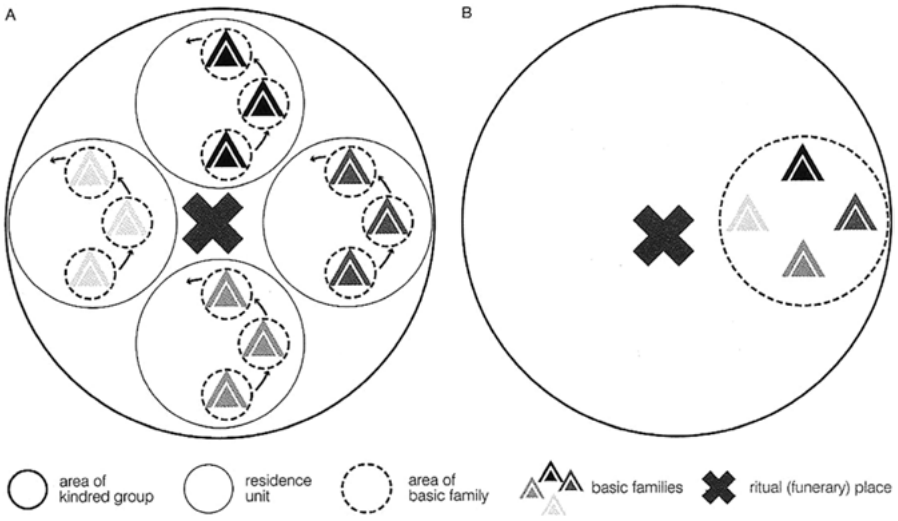


Fig. 5.1 | Proposed model for a social organisation and settlement structure of the Globular Amphora culture in Kuyavia (after Czebreszuk/Szmyt, 2011, fig. 8).

identified. On the one hand, basic family groups move regularly between periodic camps within a wider residence unit. Ritual places are in the centre of the residence units of multiple basic family groups that build a wider kindred group (A). Several basic family groups can also commonly combine to form a larger residence group, and clustering in a hamlet of sorts and sharing a ritual place (B). Hence, Szmyt implies a cyclical component to the settlement organisation of the Globular Amphora culture communities in Kuyavia that depends on periodical dispersal and contraction.

The cattle burials or cattle depositions are relevant to this pilot-study. Cattle deposition is a more neutral term suggested by A. Pollex (Pollex, 1999, 542), since their interpretation as burials, with inferences of accompanying grave goods or sacrifices, is uncertain and still under debate. Several authors have made cattle depositions the subject of their studies, most recently Pollex (1997; 1999), Zalai-Gaál (1998), Döhle and Pape (2006), Jeunesse (2006), Szmyt (2006), and Johannsen and Laursen (2010). The earliest cattle depositions occur around the middle of the 4th millennium BC in central Germany connected with the Salzmünde culture, and in the Polish late Funnel Beaker context. The distribution of cattle depositions is shown in Figure 5.2. The largest numbers of cattle depositions are assigned to the Globular Amphora culture, followed by the Baden complex in the Carpathian Basin. They are also known in the contexts of other cultural units such as Walternienburg and Bernburg (Zalai-Gaál, 1998; Pollex, 1999, 542, 548; Szmyt, 2006, 3; Sühs, 2007, 19).

Cattle depositions occur in a number of different variations, making an interpretation of the features difficult. Single, double and multiple cattle depositions as well as partial burials have been found. They occur with or without associated human burials or other domesticated animals (Pollex, 1999, 542, 546 fig. 2; Johannsen/Laursen, 2010, 25). The interpretation of cattle depositions has been approached from various standpoints and range from viewing the cattle as sacred (Czebreszuk/Szmyt, 2011, 278), to seeing them as offerings, for example to gods or exceptional human individuals (Behrens, 1973, 243; Beier, 1988, 63; Döhle/Pape, 2006, 88; Döhle/Schlenker, 1998, 13) or simply as paired draught animals (Döhle/Stahlhofen, 1985, 171–172; Döhle/Schlenker, 1998, 14–15; Johannsen/Laursen, 2010, 25–26). While the cattle are often arranged in pairs and can be linked to finds of wagon models, there is so far no direct evidence of wagon remains in the graves (Behrens, 1964, 71).

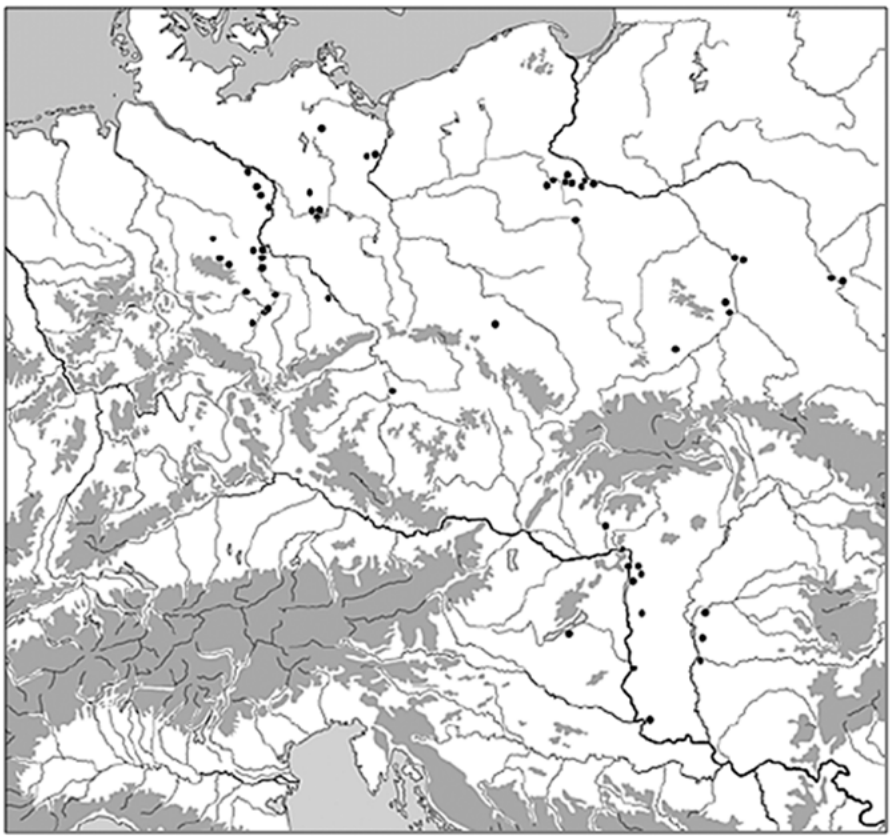


Fig. 5.2 | Distribution of Central European cattle depositions of the late 4th and early 3rd millennium BC (after Johannsen/Laursen, 2010, fig. 5, excluding the stone heap graves on the Jutland Peninsula).

5.4.2 Archaeology of Zauschwitz

The site of Zauschwitz is situated in the district of Borna in the regional district Leipzig and comprises burial and settlement structures of different time periods. The remains of Globular Amphora culture burials were discovered there in 1960 and 1961 (Fig. 5.3). A pit containing a triple cattle deposition was excavated in 1960 and has been culturally assigned to the Globular Amphora culture (Behrens, 1964, 104–105; Beier, 1988, 62; Döhle, 1988, 28–36). The cultural context of two single cattle depositions without burial objects at the same site is, however, uncertain (Beier, 1988, 62). The three cattle were found in a pear-shaped E–W oriented burial pit of 4.75 m in length and 1.5 m to 2.7 m in width and deposited in W–E (cattle I) and E–W (cattle II, III) direction. While cattle I was placed on its right side on the western side of the grave, cattle II and III were placed in 'sitting' or crouched positions to the east of the first animal (Coblenz/Fritzsche, 1961, 62–69). Cattle I was a cow of 7 to 9 years, while cattle II and III were between 5 and 7 years of age and male (Döhle/Schlenker, 1998, 26; age statement in Jeunesse, 2006, 257; Sühs, 2007, 20–21). A comparison to the cattle deposition in Oschersleben lead Döhle and Schlenker (1998, 27–28) to suggest an interpretation of a yoke of two oxen pulling a wagon with a cow. This interpretation is open to question because of the short distance between the female cattle and the two male ones. Seven ceramic vessels were found in the burial pit arranged near the heads of the cattle (Weber, 1964, 137–138).

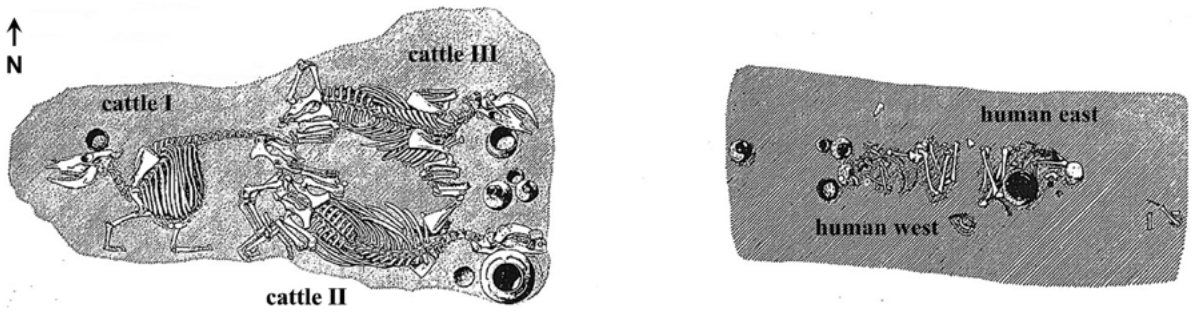


Fig. 5.3 | Triple cattle deposition and double human burial in Zauschwitz (modified after Coblenz/Fritsche, 1962, fig. 1).

A double human burial with marked similarities to that of the cattle was discovered nearby and excavated by K. Fritzsche in 1961. Due to the burial objects, the similar orientation, depth and short distance from the cattle deposition, the two burials are assumed to be contemporaneous. The double burial consisted of an eastern and a western individual laid in an almost rectangular flat grave measuring 4.2 m in length and 1.60 m to 1.80 m in width. They were oriented E–W at either end of the grave, which was also oriented E–W. The eastern skeleton was an old male buried in a crouched position on the left side, facing south. The western skeleton was a juvenile, probably male individual in a crouched position on the right side also facing south. The grave goods included five ceramic vessels, three of which were globular amphorae, two flint axes, one bone awl, one boar tooth, and unworked animal bones and teeth (Coblenz/Fritzsche, 1962, 77–82; Behrens, 1964, 104–105).

The two complexes are well suited for a comparison between human and faunal mobility through stable isotope analysis due to their chronological and spatial proximity.

5.5 Expected isotopic values of Zauschwitz

The site is located at the western margin of the Elster river valley on a plain of Cenozoic sediments (Fig. 5.4). The geological map shows Cambrian and Triassic bedrock less than 20 km from the site. Metamorphic rocks of Proterozoic and Cambrian ages, Palaeozoic plutonites, Ordovician and Carboniferous rocks occur further south, southeast and east. The area further to the west is largely dominated by Triassic rocks. Plains with young sediments continue to the north and northeast. According to the $^{87}Sr/^{86}Sr$ map of mineral waters (Voerkelius et al., 2010), $^{87}Sr/^{86}Sr$ values in the range of 0.709 to 0.711 can be expected for the site of Zauschwitz.

De Jong et al. (2010, 127 fig. 3) measured $^{87}Sr/^{86}Sr$ in sediments in the wider surrounding of the site of Eulau, less than 25 km southwest of Zauschwitz. They found the sediment of the area to range from below 0.710 to 0.712, while the $^{87}Sr/^{86}Sr$ in the eastern forelands of the Harz Mountains in the vicinity of Palaeozoic geology was highly variable due to erosion and featured values from below 0.710 to above 0.712. Based on recent and archaeological baseline samples Knipper et al. (2012, 297 fig. 7) estimated the 'regional' $^{87}Sr/^{86}Sr$ span of two early medieval cemeteries in the Thuringian Basin to range between approximately 0.708 and 0.711, including different geological regions (cf. also Maurer et al., 2012).

According to the Online Isotopes in Precipitation Calculator, the OIPC (Bowen, 2010; www.waterisotopes.org), the annual average $\delta^{18}O$ values in modern precipitation range around –8.8 ‰, which is in

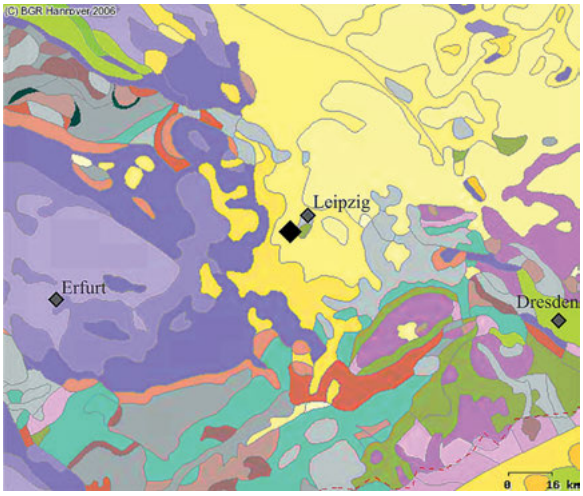


Fig. 5.4 | Geological map (based on Asch, 2005; scale 1.016.969) of the region around Zauschwitz (black diamond).

Geological Age:
Cenozoic (yellow)
Mesozoic: Cretaceous (green), Jurassic (blue), Triassic (purple)
Palaeozoic: Permian (auburn), Carboniferous (grey), Ordovician (turquoise), Cambrian (olive)
Precambrian: Proterozoic (dark pink), Archaean (light pink)

The map of $^{87}Sr/^{86}Sr$ results from natural mineral waters (Voerkelius et al., 2010, fig. 1) suggests $^{87}Sr/^{86}Sr$ ranges of 0.709 to 0.711 for the Cenozoic sediments, 0.707 to 0.709 for Mesozoic geology and 0.711 to > 0.720 for the Palaeozoic to Precambrian geology of the Erz Mountains.

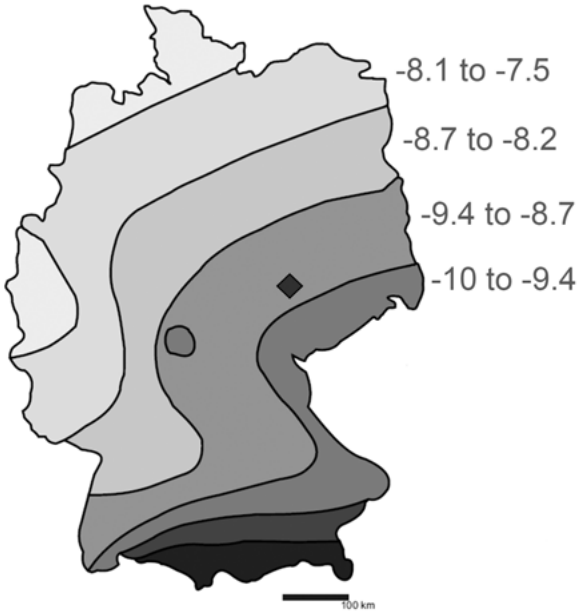


Fig. 5.5 | Annual mean $\delta^{18}O$ ratios in precipitation (‰), recorded in 1991 (modified after Knipper, 2011, 143 fig. 8.11, based on Tütken et al., 2004, fig. 8). The location of Zauschwitz is marked by a diamond.

accordance with the $\delta^{18}O$ ranges published in Tütken et al. (2004, fig. 8) (Fig. 5.5). Normal annual temperature fluctuations mean $\delta^{18}O$ values in precipitation vary between –12 ‰ and –13 ‰ in the winter month of January and –6 ‰ to –7 ‰ in the summer month of July.

5.6 Material

Both humans and all three cattle were selected for strontium and oxygen isotope analyses (Appendix A). A first and second molar (M1 and M2) were selected for analysis from each human individual. A second molar (M2) was taken from cattle I and first molars (M1) from cattle II and III. Each cattle tooth was sampled horizontally in triplicate, from the top, the centre and the bottom of the tooth. Due to incremental tooth mineralization in cattle (cf. Hillson/Antoine, 2003, fig. 6.1), a sequential sampling along the growth axis enables patterns of movement over the time of tooth mineralization to be shown.
Two modern snails from a recent excavation in Zauschwitz were sampled to estimate the 'local' biologically available strontium in addition to three dentine samples from the human teeth to provide data on post depositional contamination, which may also help in establishing a 'local' signature.

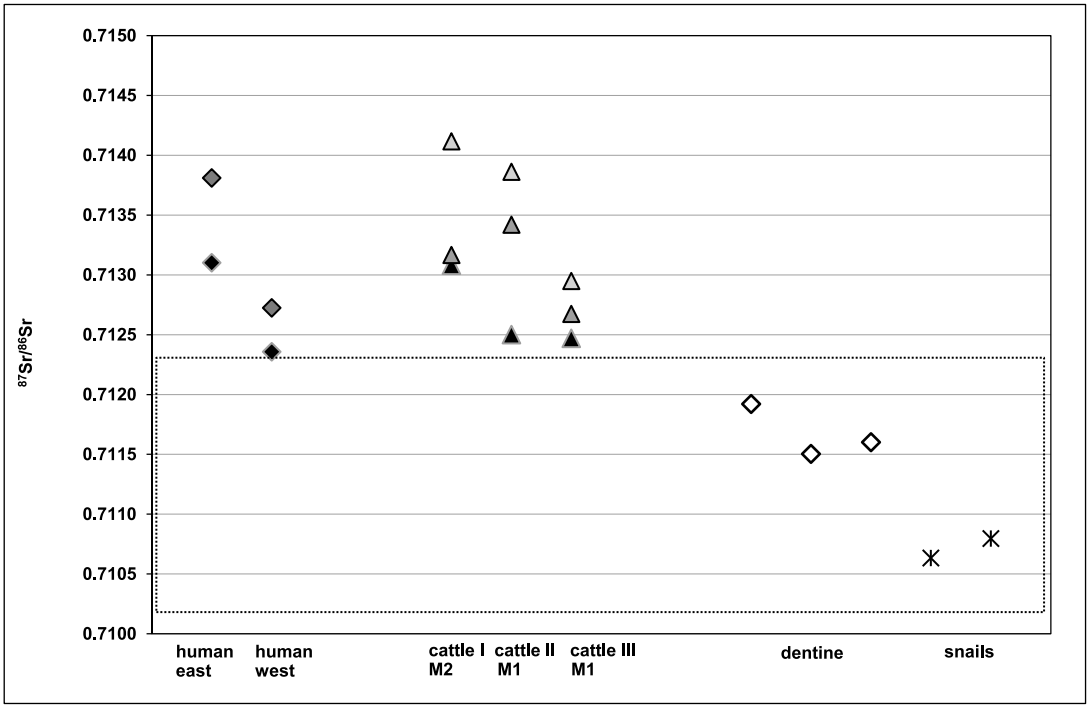


Fig. 5.6 | $^{87}Sr/^{86}Sr$ data for Zauschwitz: Humans: first molars (black diamonds), second molars (grey diamonds). Cattle: Cuspal enamel sections (black triangles), central sections (medium grey triangles), cervical sections (light grey triangles). References to establish the 'local' biologically available $^{87}Sr/^{86}Sr$: snails (crosses) and human tooth dentine (diamonds).

5.7 Results and discussion

5.7.1 Strontium isotope analysis

The $^{87}Sr/^{86}Sr$ results are presented in Figure 5.6. The four samples deriving from two human individuals had an average $^{87}Sr/^{86}Sr$ ratio of 0.71300 ± 0.00061 (1σ). The lowest $^{87}Sr/^{86}Sr$ ratio came from the first tooth (M1) sampled of the western skeleton (0.71236), the highest $^{87}Sr/^{86}Sr$ ratio was from the second tooth (M2) of the eastern skeleton (0.71381). A significant increase in $^{87}Sr/^{86}Sr$ ratios can be observed between the first and second molars of each human. The second molar of cattle I and the first molars of cattle II and III gave increasing $^{87}Sr/^{86}Sr$ ratios from the top representing the oldest material to the bottom of the sampled teeth representing the youngest material. The mean value of 0.71314 ± 0.00058 (1σ) is very similar to the average of the human $^{87}Sr/^{86}Sr$ ratios. There is a large span between the minimum (0.71247) and the maximum (0.71412) values.

Two snail shells from an excavation of the nearby Neolithic settlement and three dentine samples were used to establish a 'local' $^{87}Sr/^{86}Sr$ signature. The reference samples had a mean of 0.71129 ± 0.00055 (1σ), which is more than 0.0015 less radiogenic than the lowest tooth enamel value. Considering the large deviations between tooth enamel, the dentine and the snails, it can be suggested that the burial environment has a significantly less radiogenic $^{87}Sr/^{86}Sr$ ratio than the teeth. In that case the dentine would represent a partly diagenetically altered $^{87}Sr/^{86}Sr$ signal, which might be the result of a mixed

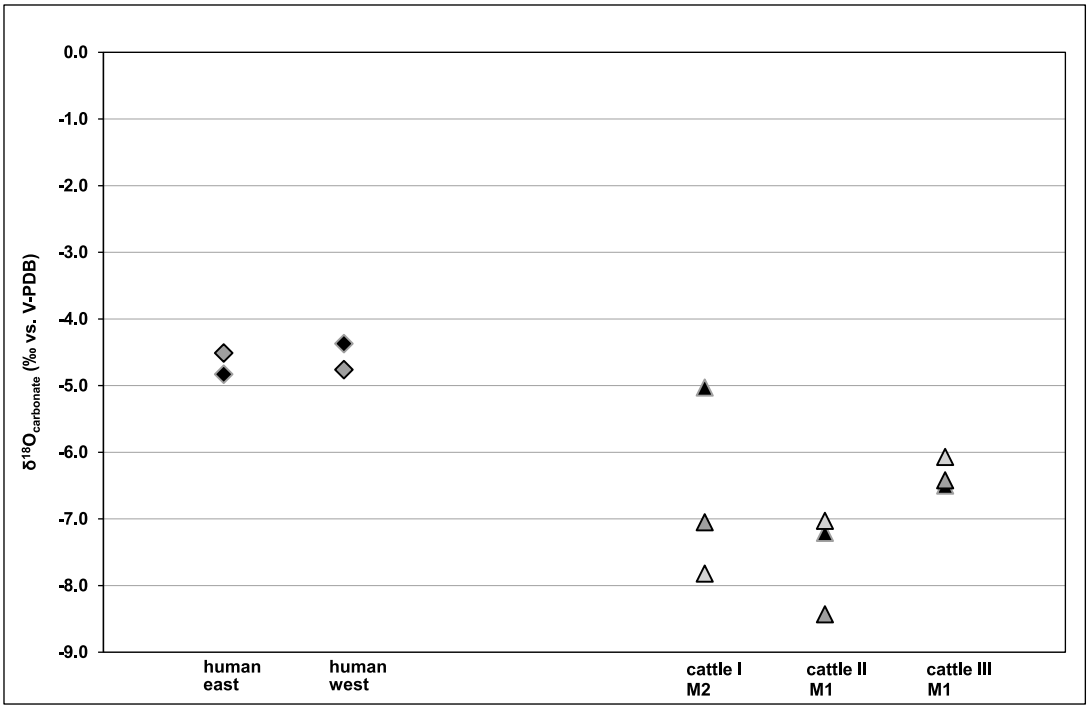


Fig. 5.7 | $\delta^{18}O_{carbonate}$ (V-PDB) data for humans and cattle from Zauschwitz: Humans: first molars (black diamonds), second molars (grey diamonds). Cattle: Cuspal enamel sections (black triangles), central sections (medium grey triangles), cervical sections (light grey triangles).

signal of different geologies and not necessarily equal the 'local' biologically available $^{87}Sr/^{86}Sr$ for the site.

Furthermore, the Cenozoic geology of the surrounding area, with expected $^{87}Sr/^{86}Sr$ ratios of approximately 0.709 to 0.711, fits with the results from the two snail samples. Studies in Saxony-Anhalt, however, showed that loess can produce $^{87}Sr/^{86}Sr$ values of up to 0.712 (de Jong et al., 2010, 65 fig. 3). Even more radiogenic ratios can probably be found in the low mountain ranges to the south and to the southeast with $^{87}Sr/^{86}Sr$ ratios above 0.713 (cf. Voerkelius et al., 2010, fig. 1).

Despite the wide 'local' $^{87}Sr/^{86}Sr$ range from 0.7102 to 0.7124 derived from the reference samples, all the tooth enamel $^{87}Sr/^{86}Sr$ ratios lie above that range. The sample from the first molar of the right crouched burial and the top sections of the second molars of cattle II and III are only slightly more radiogenic. All other values, however, are considerably more radiogenic than the estimated 'local' strontium range.

5.7.2 Oxygen isotope analysis

The $\delta^{18}O_{carbonate}$ (V-PDB) results are presented in Figure 5.7. The four samples from the two humans have a very narrow range of –4.83 to –4.37 ‰ with a mean of –4.63 ± 0.21 ‰ (1σ). The teeth of the three cattle presented much more varying values, between –8.43 and –5.03 ‰, with a mean of –6.86 ± 0.99 ‰ (1σ).

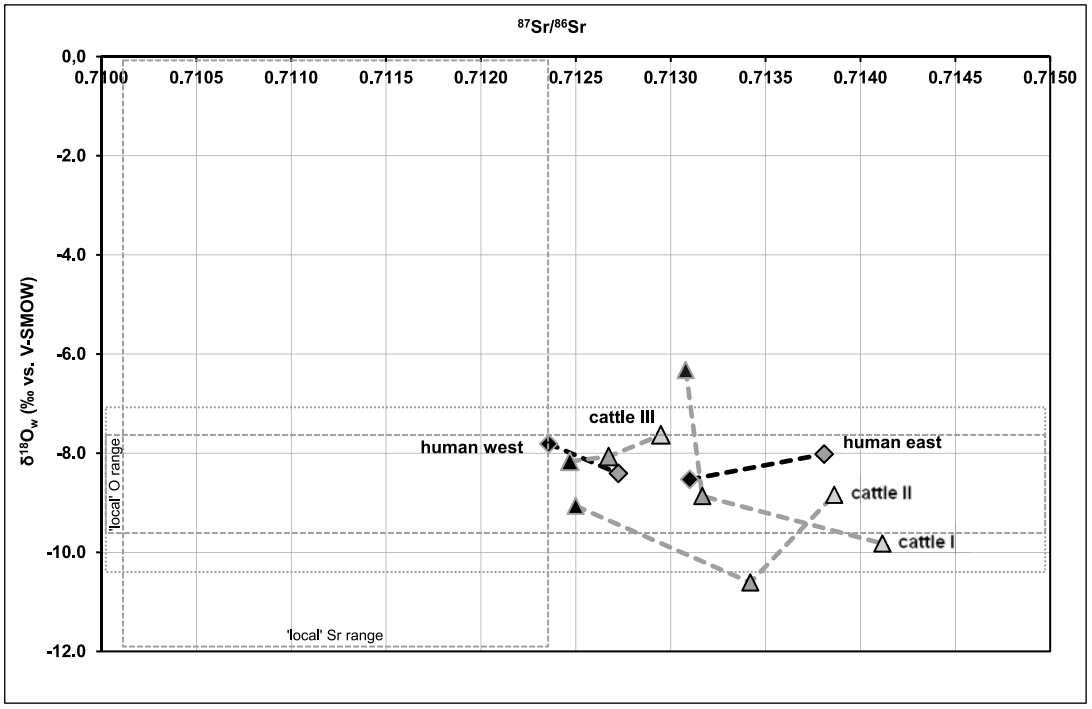


Fig. 5.8 | Combined $^{87}Sr/^{86}Sr$ and $\delta^{18}O_{water}$ data for the sampled tooth enamel from Zauschwitz: Humans (diamonds; using the equation by Longinelli, 1984), cattle (triangles, using the equation by D'Angela/Longinelli, 1990). Teeth and tooth sections from the same individual are linked by dotted lines. Estimated 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ ranges are outlined in grey.

In order to compare $\delta^{18}O$ values in modern precipitation, the $\delta^{18}O_{carbonate}$ (V-PDB) were converted into $\delta^{18}O_{water}$ ($\delta^{18}O_w$) using the equations of Longinelli (1984) for humans[2] and D'Angela and Longinelli (1990) for cattle[3] (Appendix C Tables 1, 3). The two humans gave $\delta^{18}O_w$ values between –8.53 to –7.81 ‰ with a mean of –8.19 ± 0.34 ‰ (1σ) and a median of –8.22 ‰. The teeth from the three cattle had more depleted and more variable values between –10.61 and –6.33 ‰ (using the equation of D'Angela and Longinelli (1990), equation 1) or between –11.37 and –6.46 ‰ (using the equation of Hoppe (2006), equation 3). Using equation 1 the $\delta^{18}O_w$ mean for the cattle was –8.60 ± 1.25 ‰ (1σ), the median was –8.84 ‰. Using equation 3 the $\delta^{18}O_w$ mean for the cattle was –9.07 ± 1.43 ‰ (1σ), the median was –9.34 ‰.

The mean and the median of the $\delta^{18}O_w$ values from the humans and the cattle roughly agrees with the OIPC annual $\delta^{18}O$ mean of approximately –8.80 ‰. Hence, the 'local' $\delta^{18}O_w$ range can approximately considered to fall between –9.8 ‰ and –7.8 ‰ or between –10.4 ‰ and –7.2 ‰, in respective to the wider frame. The narrow frame covers most samples, while two cattle tooth values are more depleted and one more sample is less depleted than the narrow range of the estimated 'local' $\delta^{18}O_w$ range.

2 The equation by Longinelli (1984) was applied for reasons of comparability to further data from the University of Bristol (see Appendix C Table 1 for further conversion equations).

3 Cf. Appendix C Table 3 for further conversion equations.

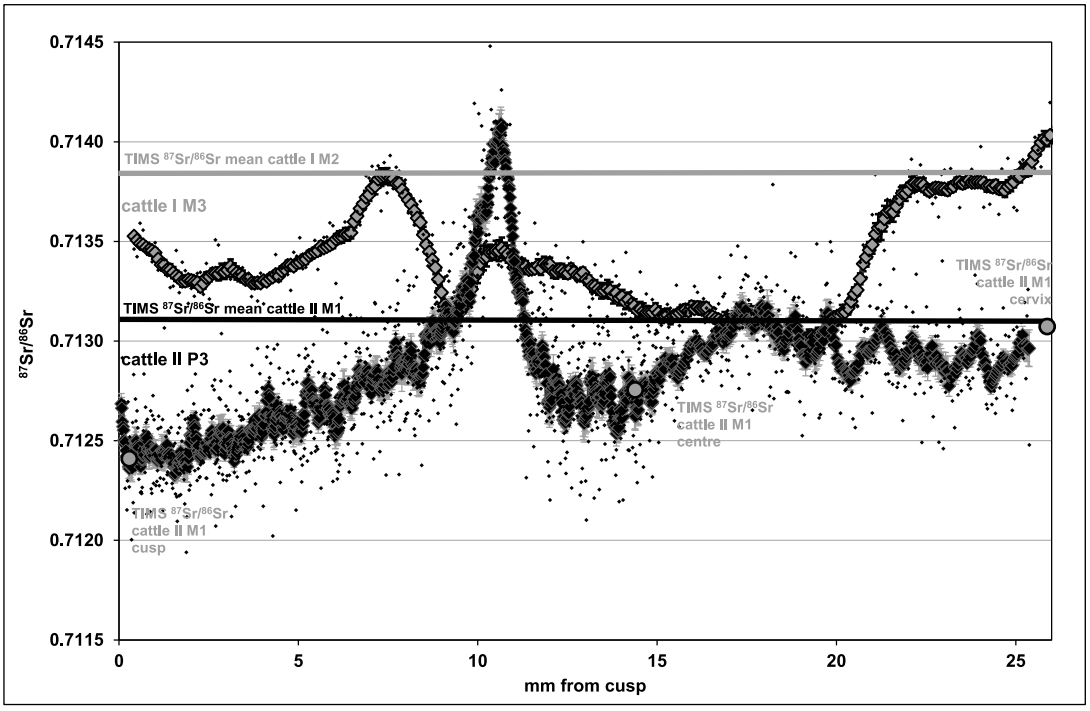


Fig. 5.9 | $^{87}Sr/^{86}Sr$ data for cattle I maxilla M3 and cattle II maxilla P3 using $^{87}Sr/^{86}Sr$ laser ablation MC-ICP-MS analysis, including ± 1σ. LA-MC-ICP-MS analysis was performed at the National Oceanography Centre facilities at the University of Southampton. For methodological details see de Jong et al., 2010; de Jong et al., in prep.

5.7.3 Combination of strontium and oxygen isotope analyses

The combined $^{87}Sr/^{86}Sr$ and $\delta^{18}O_w$ results are presented in Figure 5.8. The 'local' $^{87}Sr/^{86}Sr$ signature for Zauschwitz ranges from 0.7102 to 0.7124 and the approximate 'local' $\delta^{18}O_w$ signature ranges from –9.8 ‰ to –7.8 ‰. The two humans have fairly consistent oxygen ratios of around –8 ‰, but very variable strontium ratios with variations of 0.017 intra- and inter-individually. Both individuals show a shift to more radiogenic geology during the first years of life. As the tooth mineralization of the old man and the juvenile man were not contemporaneous, they may still have been part of the same community, despite some variations in their $^{87}Sr/^{86}Sr$ ratios. The region(s) of origin and/or temporary stays of the two humans are geologically different but similar in climate to Zauschwitz. This scenario does not fit the high mountains or areas very far away. The Cenozoic geology in the surrounding of the site gives reason to expect $^{87}Sr/^{86}Sr$ ratios of below 0.7110. The Mesozoic rocks to the west of Zauschwitz would result in even lower radiogenic ratios. De Jong et al. (2010, 127 fig. 3) measured $^{87}Sr/^{86}Sr$ in sediments from the eastern foreland of the Harz Mountains, which are partly built by Palaeozoic rocks ranging from below 0.710 to above 0.712. $^{87}Sr/^{86}Sr$ values above 0.712 might be connected to the Palaeozoic rocks of this mountain range that is less than 50 km northeast of the study site, although there is also a small spot of Palaeozoic in the close proximity to Zauschwitz.

The cattle yielded highly variable isotopic results. The cuspal enamel section of the second molar of cattle I had a high $^{87}Sr/^{86}Sr$ ratio, which continuously increased within the tooth for the younger

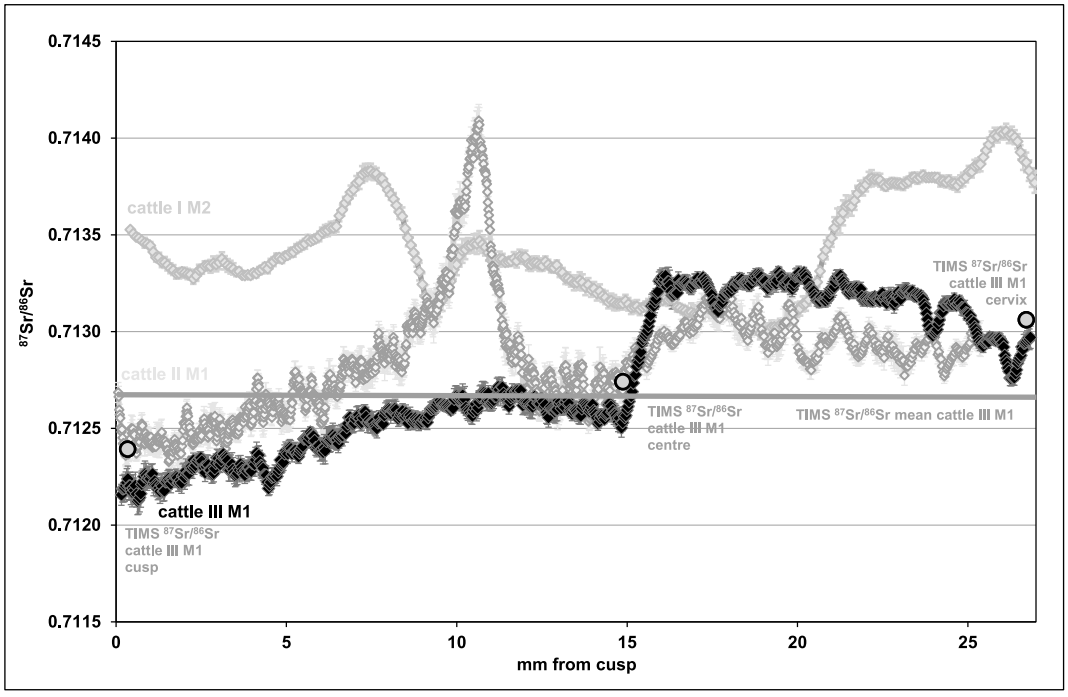


Fig. 5.10a | $^{87}Sr/^{86}Sr$ data for cattle III maxilla(?) M1 using $^{87}Sr/^{86}Sr$ laser ablation MC-ICP-MS analysis, including ± 1σ. Cattle I and II data is plotted for reasons of comparison. LA-MC-ICP-MS analysis was performed at the National Oceanography Centre facilities at the University of Southampton. For methodological details see de Jong et al., 2010; de Jong et al., in prep.

samples. The $\delta^{18}O$ values show a strong intra-tooth variance too, starting with a signal less depleted than the humans and getting more depleted along the tooth. This might be explained by seasonal movements or, even more probable, seasonal variations in temperature. The central tooth enamel section is astonishingly similar to the first molar of the eastern human burial in respect to $^{87}Sr/^{86}Sr$. The second molar in cattle approximately represents the first year of life, which is several years before the animal died. Within this year cattle I changed its location, or the isotopic region, at least twice. Adding the $^{87}Sr/^{86}Sr$ results for the third molar, which were obtained from laser ablation (Fig. 5.9), a clear hint to seasonal movement, maybe transhumance, is given. The $^{87}Sr/^{86}Sr$ values from both M2 and M3 show multiple stays in regions with the same or similar geology. One of these regions is characterised by $^{87}Sr/^{86}Sr$ values of approximately 0.7130 and less depleted $\delta^{18}O$ values, if not due to seasonal variation, while $^{87}Sr/^{86}Sr$ values around 0.7140 associated with more depleted $\delta^{18}O$ values are typical for the second region. Considering the $^{87}Sr/^{86}Sr$ values of both teeth and the $\delta^{18}O$ values of the second molar there are clear indications for movements, potentially between the lowlands and a hillier area.

First molars were selected for both, cattle II and III. In cattle, the first molar mineralizes during the first months of life. The two cattle, both male, may have been of approximately the same age at the point of death. The isotopic signals of the cuspal enamel sections are very similar, which suggests an isotopically similar region of origin. The isotopic evidence points to a different area of birth for these two cattle to the area where cattle I spent its first year. The differing isotope results of the mid-lobe and cervical tooth enamel sections indicate that they parted company after birth or that cattle II was moved somewhere else and cattle III was pastured in an area closer to the place of birth. The $^{87}Sr/^{86}Sr$ values

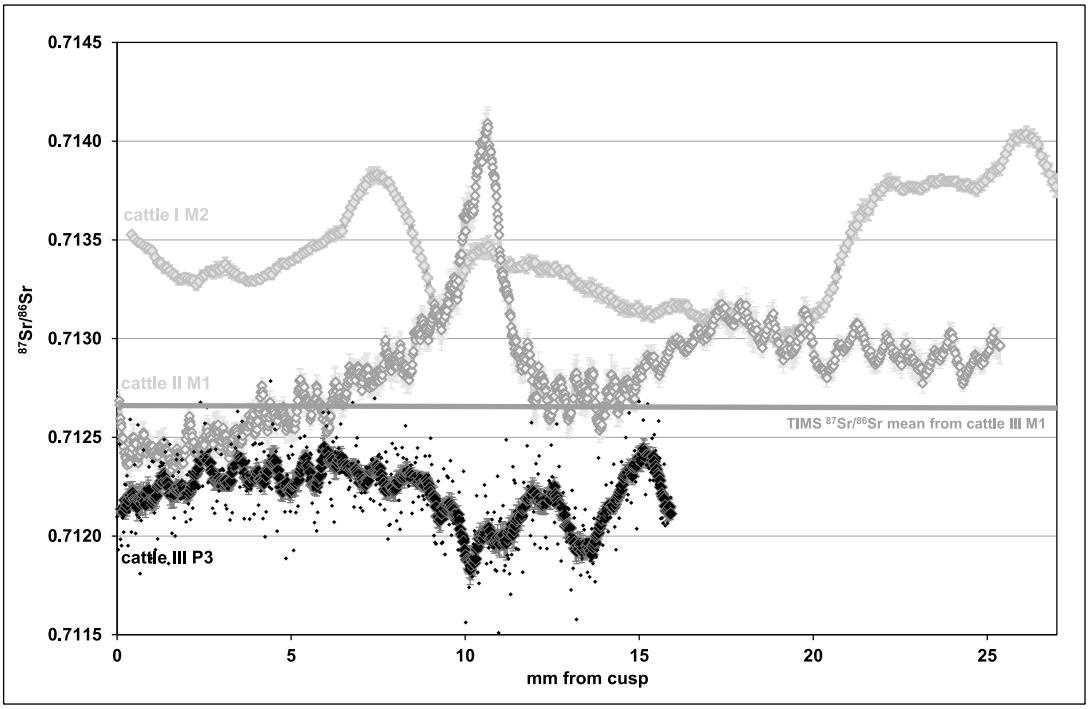


Fig. 5.10b | $^{87}Sr/^{86}Sr$ data for cattle III maxilla P3 using $^{87}Sr/^{86}Sr$ laser ablation MC-ICP-MS analysis, including ± 1σ. Cattle I and II data is plotted for reasons of comparison. LA-MC-ICP-MS analysis was performed at the National Oceanography Centre facilities at the University of Southampton. For methodological details see de Jong et al., 2010; de Jong et al., in prep.

for the second premolar of cattle II, representing the first half of the second year of age, were obtained by TIMS analysis and show a continuous increase in $^{87}Sr/^{86}Sr$ along the tooth. This signal does not clearly correlate with the $\delta^{18}O$ values. P3 was analysed for $^{87}Sr/^{86}Sr$ by laser ablation (Fig. 5.9). The period of crown formation for these two teeth partly overlaps, and a peak in $^{87}Sr/^{86}Sr$ to ratios of 0.7140 is reflected in both teeth. The remaining measurements range consistently around 0.7130. The $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ pattern of cattle II, at least in the premolar, is probably not characteristic of seasonal transhumance and suggests a one-time and/or short-term stay in an isotopically divers locations. Cattle III is relatively consistent in respect to $^{87}Sr/^{86}Sr$ and $\delta^{18}O$. Still, there are differences that indicate some dietary or local changes in the first months of life. These variations might be linked to changing pastures but could also indicate dietary, possibly seasonal, changes associated with remaining local. It has been shown that there is only minor influence of the lactation period on the $\delta^{18}O$ in cattle tooth but a major impact of seasonal and yearly variations in the $\delta^{18}O$ composition of meteoric water (Higgins/MacFadden, 2004; Zazzo et al., 2002). Comparisons to modern cattle show that supplementary feeding is usually initiated after three weeks of a cattle's life and lactation ends after around 13 weeks (Hampel, 2005; Knipper, 2011, 304). It is therefore suggested that the shift in $^{87}Sr/^{86}Sr$, which becomes particularly apparent in the results obtained by laser ablation for the same tooth (Fig. 5.10a), points to changes due to lactation and/or the initiation of supplementary feeding. Both relatively consistent $\delta^{18}O$ values in the first molar and the $^{87}Sr/^{86}Sr$ values of the third premolar (Fig. 5.10b) speak against the interpretation as movements associated with transhumance but might be indicators of fairly constant and local stays.

The comparison of the isotope values in humans and cattle is rather complicated according to the varying $\delta^{18}O_c$ to $\delta^{18}O_w$ conversion equations (cf. Appendix C Tables 1, 3). In respect to the $^{87}Sr/^{86}Sr$ signatures cattle III approximately correspond with the western human burial, whereas the mid-lobe section of the second molar of cattle I agrees with the eastern human burial. This suggests places of origin or temporary stays with similar $^{87}Sr/^{86}Sr$ signature of cattle I and the eastern human as well as cattle III (and II) and the western human, but due to the discrepancies in the age at death this seems rather improbable. It is possible, however, that the humans followed a semi-mobile or mobile way of life and revisited certain specific locations regularly, which is suggested by the model developed by Czebreszuk and Szmyt (2011, fig. 8a). If it is assumed that the isotopically similar signatures correspond to the same actual places, differences in water sources for cattle and humans could account for the variations in $\delta^{18}O$. This is contradicted by the value of cattle III though, which agrees perfectly with the humans.

Indications for varying herd management were observed in cattle from Anglo-Saxon sites in Britain using $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses (Evans et al., 2007). Early Bronze Age cattle from Irthlington and Gayhurst, Britain, however, were mainly of local origin according to their isotopic values (Towers et al., 2010). Prehistoric cattle deposited at Durrington Walls were found to have been moved over significant distances and are interpreted as imports contributing to feasting activities, while still showing considerable within-tooth variation, which suggests the exposure to different patterns of movement during the period of tooth development (Viner et al., 2010). $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analysis of faunal remains suggested small-scale animal husbandry in the vicinity of the *Linearbandkeramik* settlement of Hilzingen (Knipper, 2010, 80–84) and at the Iron Age site Eberdingen-Hochdorf the isotopic values points to the use of high quality soils in the direct surrounding of the site for crop cultivation, while animal herding took place in the direct vicinity as well as further away (Stephan et al., 2012).

5.8 Conclusions Chapter 5

Two human individuals and three cattle from burials with Globular Amphora culture context in Zauschwitz were selected for $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses. Based on the small amount of data available, conclusions must necessarily remain hypothetical. An interpretation of the data is certainly less than ideal without a good basis of reference samples. Nevertheless, it has been shown that a significant level of mobility is evidenced by the results of the $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses. The model of a periodic semi-nomadic lifestyle in association with camps and hamlets proposed by M. Szmyt for the Kuyavian region is probably transferable to the Middle Elbe-Saale region (pers. comm. M. Woidich). The results of the isotope analysis confirm a high degree of mobility for the three cattle in Zauschwitz. It is striking that the isotope values of the two male cattle, which might be of the same age, suggest a common region of origin, but in respect to the isotopes, different first months of life. Generally speaking, the isotopic signals suggest seasonal mobility (cattle I) or one-time migration, for example through trade (cattle II), but also limited mobility (cattle III). Due to the long period of human tooth enamel mineralization over several years, the isotopic signal of the humans is likely to reflect a mixture of several, probably seasonal, residences and does not necessarily imply a local restriction. Furthermore, it can be said that none of the isotope values, except the first molar of the western burial, agrees with the 'local' $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ ranges. Even the 'local' origin of this individual needs to be questioned, because human dentine values were included in the calculation of the 'local' $^{87}Sr/^{86}Sr$ range. Measurement results of laser ablation MC-ICP-MS on the same and additional teeth from the three cattle confirmed the results obtained by con-

ventional TIMS-measurement. Therefore, it is suggested that both the humans and the cattle originated somewhere else. The isotopic values may suggest the low mountain ranges in the south and southeast of the study site or the Harz Mountains in the northwest as potential places of origin, while the closer areas to the northeast and west can potentially be excluded because of the $^{87}Sr/^{86}Sr$ ratios expected there. However, the geology of the region is extremely variable and potential places of origin might be located even closer. Nevertheless, regions with similar $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ further away are equally probable places of origin and without extensive baseline sampling interpretation remains speculative.

6 Palaeodiet

6.1 Introduction

6.1.1 Objectives of this study

The reconstruction of mobility and dietary patterns are the two main issues that are addressed in this study. Questions of mobility were addressed using strontium ($^{87}Sr/^{86}Sr$) and oxygen ($\delta^{18}O$) isotope analysis. The aim of the research described in this chapter is to investigate ancient human diet and subsistence using carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analysis. Samples were selected from three sites in the West Pontic, four sites in the North Pontic and one site in the Kuban region dating to the Eneolithic and Bronze Age periods to investigate dietary patterns and possible chronological and spatial differences on an intra- and inter-site as well as inter-regional basis.

6.1.2 Diet of the West Eurasian steppe people in the Eneolithic, the Early and Middle Bronze Age

The subsistence economies of the steppe communities during the periods under discussion have already been outlined in chapter 2.1. At this point, there follows a summary of the possible subsistence and dietary components of these communities drawn from current archaeological evidence and ethnographic parallels. The burials associated with the Early Bronze Age communities are still of paramount interest in archaeological research, whereas the contemporaneous settlements are less well known or examined. While few settlements can be attributed to the Yamnaya culture, more sites seem to be associated with the Eneolithic period and Catacomb culture (Bunyatyan, 2003, 274–276). Research undertaken at these settlements rarely includes palaeobotanical analysis (Černych et al., 1998, 234; O'Connell et al., 2003, 253), so information about the subsistence economy usually comes from archaeozoological remains. Archaeozoological analyses from the small number of excavated Yamnaya settlements along the river Dnieper suggest an economy that focused on cattle and to a lesser degree on sheep herding (Kaiser, 2010a, 194–195; Benecke, 1998, 92 fig. 1). Meat was consumed on a seasonal basis and tended to vary within the nomadic steppe groups (Privat, 2004, 39 citing Толстова, 1963). Stable isotope analysis of human individuals from Bol'shekaraganski (Sintashta, early 2nd millennium BC) provided evidence of a diet rich in protein from sheep and cattle with limited input from plant based foods (Privat, 2002, 168–170).

In addition to herding, Early Bronze Age communities went fishing, hunted and gathered edible plants (Shishlina et al., 2008, 240–246). Shilov (1989, 124) concluded from the predominance of domesticates in funerary deposits from the North Pontic region that hunting and fishing were of lower importance, although the finds in burials are certainly not representative of day-to-day subsistence activities. Archaeological research in the northwest Caspian region, including palaeobotanical analysis, suggests that herds of predominantly sheep/goat were pastured on areas covered with grasses, goosefoot and amaranth. Although most archaeologists consider semi-nomadic pastoralism to have been the main subsistence economy of the Early Bronze Age steppe communities (Hollund et al., 2010, 2973),

additional agricultural activities were not rejected. There is to date, however, only indirect evidence for intensive cultivation on the steppes during the Bronze Age in general (Černych et al. 1998, 234–244; Kohl, 2002, 164 citing Гайдученко, 1999). For the North Pontic region, grain impressions in pottery provide evidence for domesticated plants such as barley, wheat, einkorn, millet, pea, bitter vetch, hemp and flax from as early as the Neolithic (Motuzaite-Matuzeviciute et al., 2009, 54). Pashkevich (2003) regards wheat, barley and proso millet as major crops in the steppe region during the Bronze Age, based on macrofossils and grain impressions. According to Kuzminova, millet was extremely popular in the Yamnaya populations (Bunyatyan, 2003, 274 citing Кузьминова, 1990). An additional suggestion of some kind of agricultural activities comes from the presence of grinding stones and horn mattocks in Yamnaya graves (Bunyatyan, 2003, 276; Kohl, 2007, 144), but the possibility of cereals being imported and the use of sickles for harvesting hay and wild plants cannot be excluded (Boroffka/Mantu-Lazarovici, 2011, 155; Dergačev/Bočkarev, 2006, 379–387; but cf. also Shishlina, 2001a, 359). Neither burnt cereals, grain impressions in ceramics, nor the presence of sickles provide indisputable evidence for agricultural activities, nor do recent studies provide certain proof of crop cultivation in the steppe region (Koryakova/Epimakhov, 2007, 65, 89; Boroffka/Mantu-Lazarovici, 2011). In general, Kohl (2007, 144) describes the Early Bronze Age steppe economy as being generally based on herding, but including 'sporadic agriculture'.

The importance of freshwater fish as a dietary component of the prehistoric steppe population has been highlighted in several stable isotope studies (e.g. O'Connell et al., 2003; Privat, 2004; Privat et al., 2007; Shishlina et al., 2007; 2012; Lillie et al., 2011 incl. older lit.). Considering that Early Bronze Age steppe groups are believed to have moved along river valleys in seasonal cycles (cf. e.g. Shishlina 2001a, 357–359; Bunyatyan, 2003, 276), fluvial food can be expected to account for a certain proportion of the diet. The impact of fish and milk products is also highlighted in ethnographic studies on nomadic steppe tribes, which indicate that fish played an important role in the diet and that milk products were a central dietary staple of many steppe groups throughout the year (e.g. Golden, 2008).

6.2 Methodological basics

6.2.1 Potential information derived from light stable isotope analysis

$\delta^{13}C$ and $\delta^{15}N$ analyses of archaeological skeletal remains are well-established methods for reconstructing prehistoric human and faunal nutritional behaviour (for a detailed discussion see Schwarcz/Schoeninger, 1991; Sealy, 2001; Katzenberg, 2008). The technique allows direct assessment of distinguishable isotopic signatures in various dietary pathways and protein sources that are passed up the food chain following predictable patterns (DeNiro/Epstein, 1978; Schoeninger/DeNiro, 1984; Ambrose/Norr, 1993). Stable isotope analysis can be applied to the organic component of bone as well as on tooth apatite. While tooth apatite is an archive of human diet during childhood, bone collagen records dietary information during the last decades or years of life. Tooth dentine captures the dietary signal of the years when it mineralized, this being similar, but not identical, to the time span that the enamel of the same tooth took to mineralise (Sealy et al., 1995, 290). The application of the technique to bone is more established, due to insoluble molecules in bone that are protected by biological apatite, which undergo little diagenetic alteration (Hillson, 1996, 224; Grupe/Peters, 2009, 277). The denaturation of bone collagen is caused by the break of hydrogen bonds and the subsequent dissolution of

fibrils. However, despite the degradation of the collagen molecules, the original collagen's isotopic composition remains unchanged (Lee-Thorp, 2008, 930). Stable isotopes in bone collagen represent averages of long-term climatic and dietary conditions, depending on the remodelling interval of the bone sampled (Sealy et al., 1995, 290–291; Grupe/Peters, 2009, 276). Ribs are remodelled over a relatively short period, i.e. several years, whereas long bones represent the mean diet of one to several decades of an individual's lifetime (Sealy et al., 1995, 291; Chenery et al., 2010, 152; Reitsema et al., 2010, 1416). A radiocarbon based study showed that the turnover of bone slows dramatically after full maturity is achieved (Hegdes et al., 2007).

The carbon in bone collagen predominantly derives from dietary protein but may also reflect dietary carbohydrates and lipids, particularly when protein levels are low in the diet, as shown by controlled feeding experiments (e.g. Ambrose/Norr, 1993). Nitrogen, on the other hand, may mostly be obtained from dietary protein. There are some issues concerning the synthesis of non-essential amino acids, however (Jim et al., 2006 with further references), and consequently carbon and nitrogen isotope analysis tends to reflect the main protein sources rather than the whole diet (Reitsema et al., 2010, 1416). The analysis of $\delta^{13}C$ and $\delta^{15}N$ to understand diet is an evolving technique with issues that are not yet well understood (Lee-Thorp, 2008, 928–929).

6.2.2 $\delta^{13}C$ analysis

6.2.2.1 Basic principles

Carbon has two stable (^{12}C, ^{13}C) and several unstable isotopes. For the purposes of archaeological dietary reconstruction, the ratio of the two stable isotopes of carbon, ^{13}C (1.11 % of carbon) and ^{12}C (98.89 %) is measured and reported relative to the Vienna Pee Dee Belemnite carbonate standard (V-PDB):

$$\delta^{13}C = 1000 \times [(^{13}C/^{12}C_{sample}) / (^{13}C/^{12}C_{standard}) - 1]$$

The variation is expressed in ‰ (per mil) as $\delta^{13}C$ (Faure, 1977, 491; Schoeninger, 1985, 515; Hoefs, 1987, 32; Katzenberg, 2008, 422). $\delta^{13}C$ is commonly measured in the collagen and in the carbonate of bone and tooth. Although the combined measurement of both collagen and carbonate may be helpful yielding information not only on protein sources but further dietary components (e.g. Ambrose/Norr, 1993; Lee-Thorp/Sponheimer, 2003), only $\delta^{13}C$ in collagen was analysed in the present study, and results therefore predominantly reflect the protein component of the diet.

The application of carbon isotope analysis enables the distinction of food-webs based upon two distinctive photosynthetic plant pathways, since C_3 pathway plants and their consumers will yield relatively depleted $\delta^{13}C$ values, whereas C_4 plants and their consumers will exhibit more enriched ratios of $^{13}C/^{12}C$. Marine foodwebs may also be distinguished from C_3-based terrestrial resources via more enriched $\delta^{13}C$ values that are comparable with those exhibited in a C_4 foodweb; the stable carbon isotope signature of freshwater components, on the other hand, has been shown to exhibit significant variability (Dufour et al., 2007).

6.2.2.2 $\delta^{13}C$ in C_3 and C_4 plants and their consumers

Most plants can be classed as either C_3 or C_4 plants, according to their different pathways of photosynthesis through which atmospheric carbon is fixed in the plant tissues. Due to these photosynthetic differences, i.e. C_3 plants fractionate CO_2 to a greater degree than C_4 plants do, due to the greater need for C_4 plants to conserve water, and the $\delta^{13}C$ values in C_3 and C_4 plants are depleted in ^{13}C to different degrees, with almost no overlap (O'Leary, 1988; Sharp, 2007, 153–157). C_3 plants include temperate grasses, wheat, tree shrubs and root crops. The $\delta^{13}C$ in C_3 vegetation averages at –27 ‰ (–26 ‰ according to Prowse et al., 2005, 3), and can vary between –34 and –22 ‰ depending on temperature and precipitation (Heaton, 1999, 637; –37 to –24 ‰ after Grupe/Peters, 2009, 277; –29 to –25 ‰ according to O'Leary, 1988, 331 table 2). C_4 plants are mostly tropical and sub-tropical grasses that have a $\delta^{13}C$ mean of –12.5 ‰ (Hillson, 1996, 224; –13 ‰ according to Iacumin et al., 1996, 16, –12 ‰ after Grupe/Peters, 2009, 277). C_4 vegetation favours arid and warm environments and therefore gives results with low $\delta^{13}C$ variation of –17 to –9 ‰ (Bentley/Knipper, 2005, 632; –16 to –12 ‰ according to O'Leary, 1988, 331 table 2; –19 to –6 ‰ according to Faure, 1977, 491).

As well as being affected by differences in their photosynthetic pathways, $\delta^{13}C$ values in plants can also be influenced by other factors (Heaton, 1999, 645; Bentley/Knipper, 2005, 632):

1) Temperature and precipitation, i.e. more depleted values are found with increasing humidity and precipitation and less depleted values are found with higher temperatures and more arid climate (+ 0.3 ‰/°C).
2) Altitude, i.e. plants at high altitudes have slightly enriched $\delta^{13}C$ values on account of a lower partial pressure of CO_2 (+ 1 ‰/1000 m altitude).
3) Seasonal growth period, density in northern forests, i.e. more depleted $\delta^{13}C$ values are found in plants growing at the forest bottom compared to the top (1–2 ‰) (cf. van der Merwe/Medina, 1991; Drucker et al., 2008).

Animals consuming predominantly either C_3 or C_4 plants, or a mixture of both, can be determined by assessing differences in $\delta^{13}C$ values according to various proportions of each plant type. A diet based entirely on the consumption of C_3 plants will give collagen $\delta^{13}C$ values of approximately –20 ‰ in their collagen whereas a C_4 based diet will give values of ca. –8 to –7 ‰ (Sealy et al., 1995).

In general, the $\delta^{13}C$ value of bone collagen is enriched compared to the value in the diet by ~ + 5 ‰ for herbivores (Krueger/Sullivan, 1984, 214 fig. 2) with an additional fractionation factor of +1 ‰ between carnivores and herbivores (van der Merwe, 1982; Lee-Thorp et al., 1989, 592 fig. 5). Attention must be paid to variations between the $\delta^{13}C$ values of bone collagen and carbonate. There is a difference between the $\delta^{13}C$ values of the organic and mineral components of bone which lies in the region of 7 ‰ or more for herbivores, and ca. 3 ‰ for carnivores (Lee-Thorp et al., 1989, 592 fig. 5 for southern African mammals). These differences seem to reflect temperature, such that herbivores in colder regions yield more enriched values (Bocherens/Mariotti, 1992).

6.2.2.3 $\delta^{13}C$ in marine, freshwater and terrestrial diet

Besides the possible distinction of C_3 and C_4 photosynthetic plant pathways at the base of the food chain, stable carbon isotope analysis may also indicate differences in protein deriving from marine, freshwater

and terrestrial resources (Chisholm et al., 1982; Schoeninger/DeNiro, 1984; Schwarcz/Schoeninger, 1991).

As mentioned previously, bone collagen from pure terrestrial C_3-feeders is expected to exhibit $\delta^{13}C$ ratios of approximately –21 to –20 ‰ (Chisholm et al., 1982, 1132; Schoeninger/DeNiro, 1984, 635; Sealy et al., 1995, 291). Stable isotope ratios are elevated in marine environments (Sealy et al., 1995, 291) with $\delta^{13}C$ ratios between –19 and –11 ‰ (Barrett et al., 2008, 856 table 2 on cod bone; –18 to –16 ‰ in marine plants according to Grupe/Peters, 2009, 277). The mean $\delta^{13}C$ value in the collagen of a consumer of proteins mainly deriving from marine food is approximately –13 to –12 ‰ (Chisholm et al., 1982, 1131 table 1, 1132; Schoeninger/DeNiro, 1984, 635). In consequence, marine food webs exhibit very variable $\delta^{13}C$ values that may overlap with those expected for C_3 and certainly overlaps with the bulk of those expected for C_4 dietary resources (Ambrose/Norr, 1993, 3). Excluding the consumption of C_4 plants thus simplifies the distinction between marine and terrestrial food sources (Schoeninger/DeNiro, 1984, 637).

The identification of a diet where the majority of protein derives from freshwater fish is more complicated. This is due to our poor understanding of freshwater ecotones and overlapping values with terrestrial food sources (Hollund et al., 2010, 2971–2972). A diet comprised of 100 % freshwater resources has been shown to produce a $\delta^{13}C$ average of –24 to –20 ‰ and $\delta^{15}N$ average of 16 ‰ (van der Plicht et al., 2006, table 1). There is huge intra-ecosystem and intra-species variability (e.g. Dufour et al., 2007). The proportion of marine and freshwater resources in the diet is therefore very difficult to detect using isotopic signal (Hedges et al., 2004; Prowse et al., 2004). According to Higham et al. (2010, 654) the presence of freshwater resources in the diet may be indicated by very depleted or enriched $\delta^{13}C$ values compared to terrestrial C_3 plant eaters, in combination with $\delta^{15}N$ values that lie between terrestrial food consumers (low $\delta^{15}N$) and marine food consumers (high $\delta^{15}N$). While Reitsema et al. (2010, 1415) state that freshwater fish consumption is suggested from $\delta^{13}C$ ratios that are more depleted than the expected low-end member of a mainly C_3 terrestrial feeder, Lübke et al. (2009, 307) doubt the accurate use of $\delta^{13}C$ analysis in the identification of freshwater food sources. Several studies using stable isotope analysis have shown, however, that the contribution of freshwater resources creates a combination of depleted $\delta^{13}C$ and enriched $\delta^{15}N$ values. The combination of very depleted $\delta^{13}C$ ratios of approximately –23 ‰, and elevated $\delta^{15}N$ values of above 14 ‰, suggested influence from freshwater resources for the humans at the Mesolithic Iron Gate sites (Bonsall et al., 2000; cf. also Cook et al., 2001; Borić et al., 2004; Nehlich et al., 2010). Depleted $\delta^{13}C$ values around –23 ‰ and moderately elevated $\delta^{15}N$ values had also led Lillie and colleagues to argue for the supplementation of aquatic resources, i.e. freshwater river fish, to a basically terrestrial C_3 diet of the human individuals from the Dnieper Rapids cemeteries in Ukraine (Lillie/Richards, 2000, 967; Lillie et al., 2009, 261). Similar results were published by Privat (2004, table A1.9), who suggested that the presence of freshwater fish in the diet at two Eneolithic sites in Ukraine was responsible for $\delta^{13}C$ and $\delta^{15}N$ means of –23.3 ± 2.46 ‰ and –10.8 ± 2.44 ‰ respectively.

6.2.2.4 Trophic level shifts

Enrichment of stable isotope ratios from consumer to prey are observed as you go up the food chain to higher trophic levels, due to less discrimination against the heavier isotope. In $\delta^{13}C$ analysis, a trophic level enrichment of approximately 1 ‰ was identified between consumers and prey (Fig. 6.1), which is

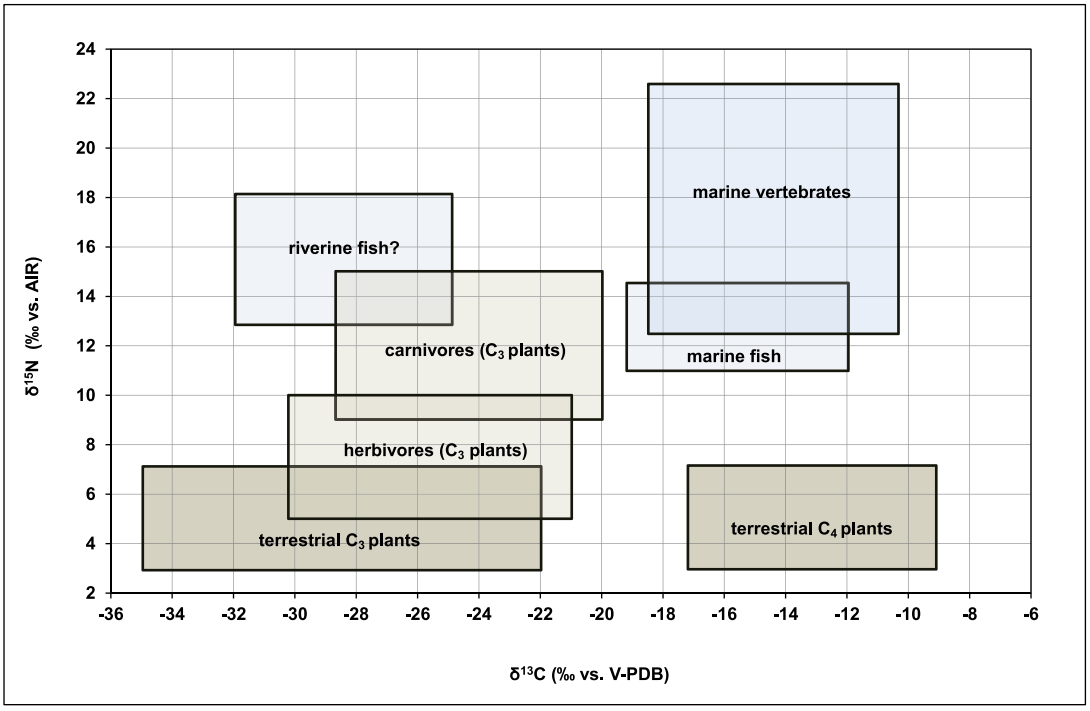


Fig. 6.1 | Model for trophic level shifts in $\delta^{13}C$ and in $\delta^{15}N$ of prey and consumers (modified after Schäuble, 2005, 149 fig. 9, 81; van der Plicht et al., 2006, table 1). Values vary significantly between different authors. In arid environments there is an additional enrichment in $\delta^{15}N$ and to a lesser extent in $\delta^{13}C$.

of minor importance due to the rather wide $\delta^{13}C$ ranges in the food sources (Schoeninger, 1985, 523; DeNiro/Epstein, 1978, 501). Other studies have indicated an approximate trophic level shift of up to 2 ‰ (Schoeninger/DeNiro, 1984; Ambrose/DeNiro, 1986; Dürrwächter et al., 2003, 41).

6.2.3 $\delta^{15}N$ analysis

6.2.3.1 Basic principles

To reconstruct past human diet, $\delta^{13}C$ analysis is applied together with $\delta^{15}N$ analysis. In the atmosphere, ^{15}N (0.36 % of nitrogen) is constant in relation to ^{14}N (99.64 %) (Faure, 1977, 513; Hoefs, 1987, 58; Schweissing, 2004, 10). $^{15}N/^{14}N$ ratios are measured and reported relative to the AIR standard (atmospheric nitrogen):

$$\delta^{15}N = 1000 \times [(^{15}N/^{14}N_{sample})/ (^{15}N/^{14}N_{standard}) - 1]$$

and expressed in per mil (‰) (Faure, 1977, 514; Schoeninger/DeNiro, 1984, 630; Schoeninger, 1985, 515).

Nitrogen is an important component of proteins and is incorporated into the food chain via nitrogen fixing organisms. Plants can also assimilate nitrogen directly (Schwarcz/Schoeninger, 1991). Nitrogen in bone collagen is entirely derived from dietary protein. Since there is a trophic level enrich-

ment in $\delta^{15}N$ values of ~ 3 to 5 ‰ from diet to consumer (e.g. DeNiro/Epstein, 1981; Schoeninger/DeNiro, 1984), $\delta^{15}N$ values reveal information about the trophic position of an individual within a localised food web. Thus, an omnivore will have more enriched $\delta^{15}N$ values than an herbivore, and carnivore $\delta^{15}N$ values will be more enriched than those of an omnivore. The higher number of trophic levels found in marine and freshwater ecosystems, where there are multiple levels of carnivores as well as carrion feeders, means that elevated $\delta^{15}N$ values will be exhibited by humans consuming a diet which included freshwater or marine protein (Schoeninger et al., 1983).

However, various other factors contribute to the variability of $\delta^{15}N$ values, complicating the interpretation of $\delta^{15}N$ results (Kjellström et al., 2009, 2691). A crucial limitation is the single reflection of dietary proteins instead the full dietary spectrum (e.g. Hedges, 2003). In addition, food sources of the same trophic level, e.g. herbivore meat and dairy products cannot be differentiated (O'Connell/Hedges, 1999; Müldner/Richards, 2007, 683). Furthermore, varying climatic conditions, subsistence techniques and animal physiology result in inter-regional variations in $\delta^{15}N$ values of plants and animal consumers (Ambrose, 1991).

6.2.3.2 Trophic level effect

Trophic level effects lead to enrichment in prey compared to consumers, leading to higher $\delta^{15}N$ values in carnivores and fish-eaters in comparison to individuals living predominantly on plant food (Fig. 6.1) (Schoeninger/DeNiro, 1984, 635). An increase in $\delta^{15}N$ values of 3 to 5 ‰ (Dürrwächter et al., 2006, 41; Hedges/Reynard, 2007, 1241). The $\delta^{15}N$ enrichment depends on species specific metabolic pathways with a mean increase with trophic level of between 3 and 5 ‰ (Bocherens/Drucker, 2003; Grupe/Peters, 2009, 278). The degree of dietary influence in comparison to physiological or genetic differences for variations in $\delta^{15}N$ is unknown. The same is true for inter-individual $\delta^{15}N$ variation, which depends on a variety of factors and can be rather large (Hedges/Reynard, 2007, 1241).

Correlated to trophic level shifts, a nursing effect is also evident in $\delta^{15}N$ values. Whilst breastfeeding, an infant's tissues will be elevated relative to the mother by 2 to 3 ‰. This is due to a trophic level increase from the mother to the infant. When the child is weaned, the $\delta^{15}N$ value decreases stepwise to its normal level (Schweissing 2004, 11; Hedges/Reynard 2007, 1241).

6.2.3.3 Terrestrial, freshwater and marine food

While $\delta^{15}N$ values in a consumer's bone collagen are relatively low with a terrestrial diet, these values will be higher where freshwater resources are consumed, and even more elevated for marine sources (e.g. Lübke et al., 2009, 309; Kjellström et al., 2009, 2691; Higham et al., 2010, 654). This is due to longer food chains in freshwater and especially marine environments, resulting in higher trophic levels of the consumers. Shorter food chains mean that key resources in terrestrial environments tend to be at relatively low trophic levels, and hence their consumers will exhibit less enriched $\delta^{15}N$ values.

$\delta^{15}N$ values for Holocene terrestrial herbivores average around 6 to 7 ‰ and for carnivores around 9 to 10 ‰, despite variations in $\delta^{15}N$ on the basis of climatic and chronological differences (Hedges/Reynard, 2007, 1241–1242). In temperate climates, $\delta^{15}N$ values of plants are around 3 ‰, for herbivores

from 6 to 7 ‰, for carnivores from 10 to 12 ‰, and in marine organisms between 10 and 20 ‰ (Dürrwächter et al., 2003). Richards and Hedges (1999) give $\delta^{15}N$ values of 4 to 10 ‰ for terrestrial herbivores, 9 ± 3 ‰ for freshwater fish and 8 to 22 ‰ for marine carnivores.

For consumers of pure marine food, $\delta^{15}N$ values average 14.8 ± 2.5 ‰ (Schoeninger/DeNiro, 1984, 631; 12 to 13 ‰ in Chisholm et al., 1982, 1132, and > 14 ‰ in Bonsall et al., 2003, 124 table 3). Freshwater fish consumption is also indicated by enriched $\delta^{15}N$ values (Schoeninger/DeNiro, 1984, 633), but there is presently no independent measurement of $\delta^{15}N$ in consumers of freshwater resources (Hedges/Reynard, 2007, 1241–1242).

6.2.3.4 Climatic effect and water dependency

Climate conditions affect the $\delta^{15}N$ values of food resources and consumers. In humid and cold areas we find low $\delta^{15}N$ values in plants compared to those from arid and warm regions, where $\delta^{15}N$ values in plants are elevated (Sealy et al., 1995, 291; Iacumin et al., 2004b, 38; Stevens et al., 2010, 54). While these climatic effects complicate inter-regional comparisons, it is useful in the determination of climatic changes. Water stress in plants results in enriched $\delta^{15}N$ values. In animals, water stress causes higher $\delta^{15}N$ values in water dependent animals like cattle and horses, compared to water conserving animals such as sheep and goat (Grupe/Peters, 2009, 278). Furthermore, it has been shown that manuring of crops leads to an enrichment in $\delta^{15}N$ of plants and their consumers (Bogaard et al., 2007).

6.3 Material

Fifty-three human bones and eight human teeth deriving from four sites in the North Pontic, three sites in the West Pontic region and one site in the Kuban region were selected for $\delta^{13}C$ and $\delta^{15}N$ analysis to shed light on the diet of the Eneolithic and Bronze Age communities in the North, the West Pontic and the Kuban region (Fig. 6.2). Samples were taken from the mid-shafts of ribs, humeri and femurs, according to availability.

To provide a firm basis for dietary interpretation, stable isotopic analysis of the most common food sources is essential, due to considerable variations between locations and time periods (van Klinken et al., 2000). Ideally, the faunal remains for the determination of the local environmental background should derive from the same sites and date to the same time periods as the human samples. Unfortunately, only a low number of mammalian bones were sampled as comparative data for the interpretation of the human isotope results. The number of samples is clearly considerably less than ideal, and resulted from a combination of low availability and the development of this research direction at a later stage in the project. Furthermore, very few faunal remains are stored from older excavations. In total, three sheep or goat bones from the kurgan Sugokleya near Kirovograd and one herbivorous animal bone from the Big Tumulus in Ovchartsi were selected, in addition to a cattle and an unspecified animal bone which were sampled from Mayaki near Odessa and Novozvanovka in eastern Ukraine.

Fig. 6.2 | Sites sampled for $\delta^{13}C$ and $\delta^{15}N$ analysis and numbers of human bone and tooth samples collected per site:
West Pontic region: Benkovski ($n_{bone} = 3$), Boyanovo ($n_{bone} = 5$), Smyadovo ($n_{bone} = 10$); North Pontic region: Kirovograd [$n_{bone} = 10$ (1 failed); $n_{teeth} = 4$, $n_{individuals} = 2$], Peshtchanka [$n_{bone} = 6$ (2 failed); $n_{teeth} = 4$, $n_{individuals} = 2$], Shakhta Stepnaya [$n_{bone} = 4$ (2 failed)], Vinogradnoe ($n_{bone} = 12$); Kuban region: Olennii ($n_{bone} = 3$).

6.4 Method

$\delta^{13}C$ and $\delta^{15}N$ isotope analyses were commissioned from the Research Laboratory for Archaeology and the History of Art (RLAHA), University of Oxford. Work was performed by E. Nitsch and supervised by R. Hedges. The preparation of bones followed the modified protocol of Bronk Ramsey et al. (2004). To summarise, 0.50 to 0.75 g of bone were shot blasted with aluminium oxide before being ground to powder. Powdered bone was then demineralised with 0.5 M HCl for 48 hours at <10 °C. The remaining residue was then rinsed with deionised Milli-Q water and placed in sealed tubes to be gelatinised with a pH 3 HCl solution at 75 °C for > 48 hours. The soluble gelatine was then filtered using 5 to 8 mm Ezee® filters (Elkay Laboratory Products) and freeze-dried for 48 hours. All insoluble residue was removed. Each sample of bulk collagen was weighed (2.0 to 3.5 mg) in triplicate into tin capsules which were analysed using an automated carbon and nitrogen analyser and a continuous-flow isotope-monitoring mass spectrometer (cf-irm-ms), an ANCA Roboprep linked to a 20/20 mass spectrometer or a Carlo Erba carbon and nitrogen elemental analyser linked to an Europa Geo 20/20 mass spectrometer. $\delta^{13}C$ and $\delta^{15}N$ measurements were made relative to the V-PDB standard and the AIR standard respectively. Repeated measurements of alanine standards were used to check the integrity of the results of each run. The analytical error for the result was ± 0.1 ‰ (1σ) for $\delta^{13}C$ and ± 0.2 ‰ (1σ) for $\delta^{15}N$ based on 62 analyses.

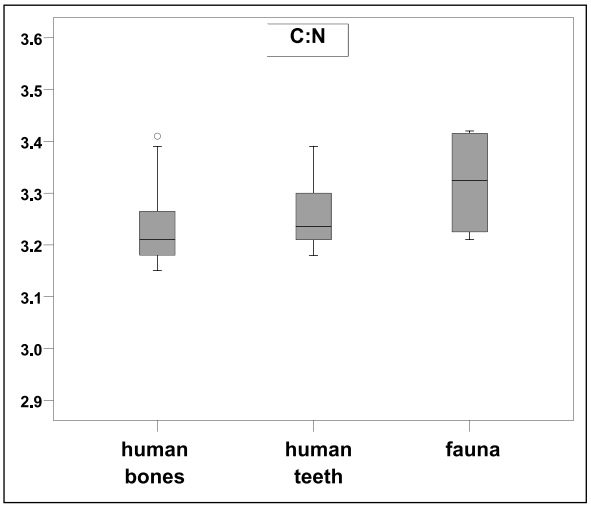


Fig. 6.3 | Box plots of the C:N yield in human bones (n = 48) and teeth (n = 8) and in the faunal remains (n = 4).

6.5 Results of $\delta^{13}C$ and $\delta^{15}N$ analysis

6.5.1 Sample preservation

Collagen preservation in bone depends mainly on temperature, time and the pH of the surrounding sediment (Nielsen-Marsh/Hedges, 2000). The ratio of carbon to nitrogen (C:N ratio) and the weight of the collagen are examined to assess the acceptability of the collagen as a sample material, since the *in vivo* abundances of the bone collagen should have survived. The accepted C:N ratios for archaeological gelatine lie between 2.9 and 3.6 (DeNiro, 1985, 807–808; in Oxford a range between 3.1 and 3.5 is accepted, van Klinken, 1999, 691), and although ratios higher than 3.6 are considered to indicate exogenous protein, extraordinarily well preserved recent skeletal remains can have C:N atomic ratios of up to 4 (Grupe/Peters, 2009, 292).

All C:N ratios of samples in this study fall within the range of acceptable values between 2.9 and 3.6 (Fig. 6.3; Appendix D Tables 1a, b). The C:N ratios of human bones range between 3.15 and 3.41 and have a mean of 3.23 ± 0.06 (1σ, n = 48). The human teeth show values from 3.18 to 3.39 with a mean of 3.26 ± 0.08 (1σ, n = 8) and the animal bone references yield C:N ratios between 3.21 and 3.42 with a mean of 3.32 ± 0.11 (1σ, n = 4).

The collagen contents for human bones range from 1.29 to 22.99 % and have a mean of 9.87 ± 4.79 % (1σ). They range from 1.82 to 15.76 % with a mean of 9.41 ± 5.56 % (1σ) for human teeth and from 4.24 to 17.04 % with a mean of 17.04 ± 5.59 % (1σ) for faunal bones. Satisfactory collagen content is expected to be > 1 % (quality guidelines by van Klinken 1999, 695). Six human bones were excluded from further analysis due to insufficient collagen content (Appendix D Table 2).

6.5.2 Results faunal material

Appendix D Table 1b provides the results from the four animal bones and the additional bones from two further sites in the North Pontic region. The animal bone from Ovchartsi is the only sample deriving

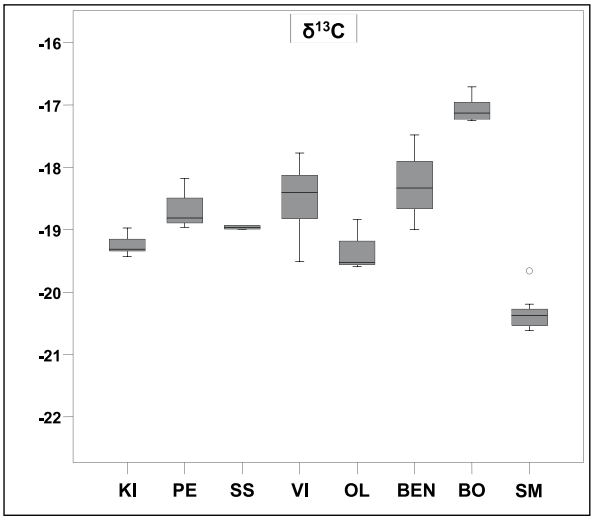


Fig. 6.4 | Box plots of $\delta^{13}C$ data for the human bone samples.

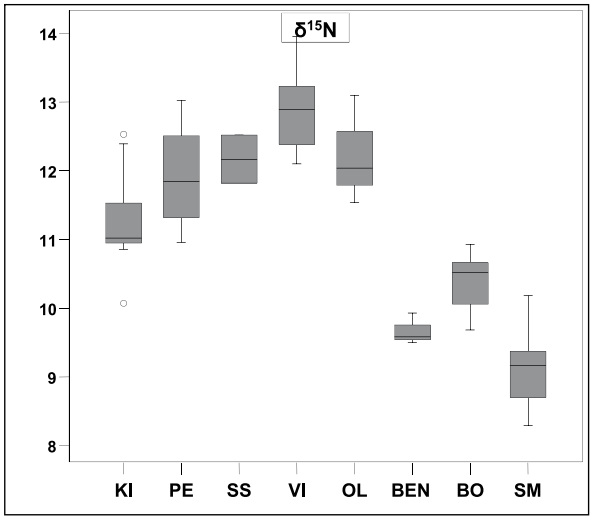


Fig. 6.5 | Box plots of $\delta^{15}N$ data for the human bone samples.

from a West Pontic site. Its $\delta^{13}C$ value of –19.4 ‰ and $\delta^{15}N$ value of 7.1 ‰ is closely comparable with the mean of the North Pontic samples (n = 3), which gave averages of –19.3 ± 0.5 ‰ and 7.3 ± 1.9 ‰ (1σ).

6.5.3 Results human material

6.5.3.1 Human bones

The results of the $\delta^{13}C$ analysis of the human bones are shown in Figure 6.4 and Appendix D Table 1a. The range of the $\delta^{13}C$ values for all individuals in the West and North Pontic and the Kuban region falls between –20.62 and –16.71 ‰ with an average $\delta^{13}C$ of –18.94 ± 1.02 ‰ (1σ, n = 48). The $\delta^{13}C$ values of the West Pontic humans are slightly more depleted, with a mean lying at –19.08 ± 1.54 ‰ (1σ, n = 18). The results for the individual sites are rather dispersed. While the human bones from Benkovski show scattered $\delta^{13}C$ values with a range from –19.00 to –17.48 ‰ and a mean of –18.27 ± 0.76 ‰ (1σ, n = 3), the individuals from Boyanovo yield the least depleted results of the complete data set (–17.25 to –16.71 ‰, mean –17.06 ± 0.22 ‰ (1σ), n = 5), whereas the human bones from Smyadovo show the most depleted values (–20.62 to –19.66 ‰, mean –20.33 ± 0.27 ‰ (1σ), n = 10). The $\delta^{13}C$ values from the North Pontic human bones are more uniform. The average $\delta^{13}C$ of the 27 North Pontic individuals sampled is –18.80 ± 0.51 ‰ (1σ). The ranges and mean $\delta^{13}C$ values from the individual sites are –19.43 to –18.97 ‰ at Kirovograd (mean –19.25 ± 0.15 ‰ (1σ), n = 9), –18.96 to –18.18 ‰ at Peshtchanka (mean –18.69 ± 0.34 ‰ (1σ), n = 4), –18.99 to –18.93 ‰ at Shakhta Stepnaya (mean –18.96 ± 0.04 ‰ (1σ), n = 2) and –19.51 to –17.77 ‰ at Vinogradnoe (mean –18.48 ± 0.53 ‰ (1σ), n = 12). The human bones from Olennii in the Kuban region yielded $\delta^{13}C$ results that lie between the West and North Pontic results. The average $\delta^{13}C$ is –19.31 ± 0.42 ‰ (1σ), and the values range from –19.59 to –18.84 ‰ (n = 3).

A Shapiro-Wilk test was applied to test the assumption of a normal distribution of the data. For all sites except the West Pontic sites (p = 0.002) and Smyadovo (p = 0.04) the null hypothesis that the data

follows a random distribution cannot be rejected at a 5% level of significance. All other sites are normally distributed. Therefore, a one-way ANOVA was performed to reveal differences between the sites ($F = 40.53$, $p < 0.001$). Statistically significant differences ($p < 0.05$; Tukey's HSD post hoc test) were observed between Smyadovo and all other sites as well as Boyanovo and all other sites. Furthermore, there were differences between Kirovograd and Vinogradnoe and Benkovski, Vinogradnoe and Olennii, and Olennii and Benkovski. A p-value of 1, on the other hand, could be observed between the $\delta^{13}C$ mean values of Kirovograd and Olennii.

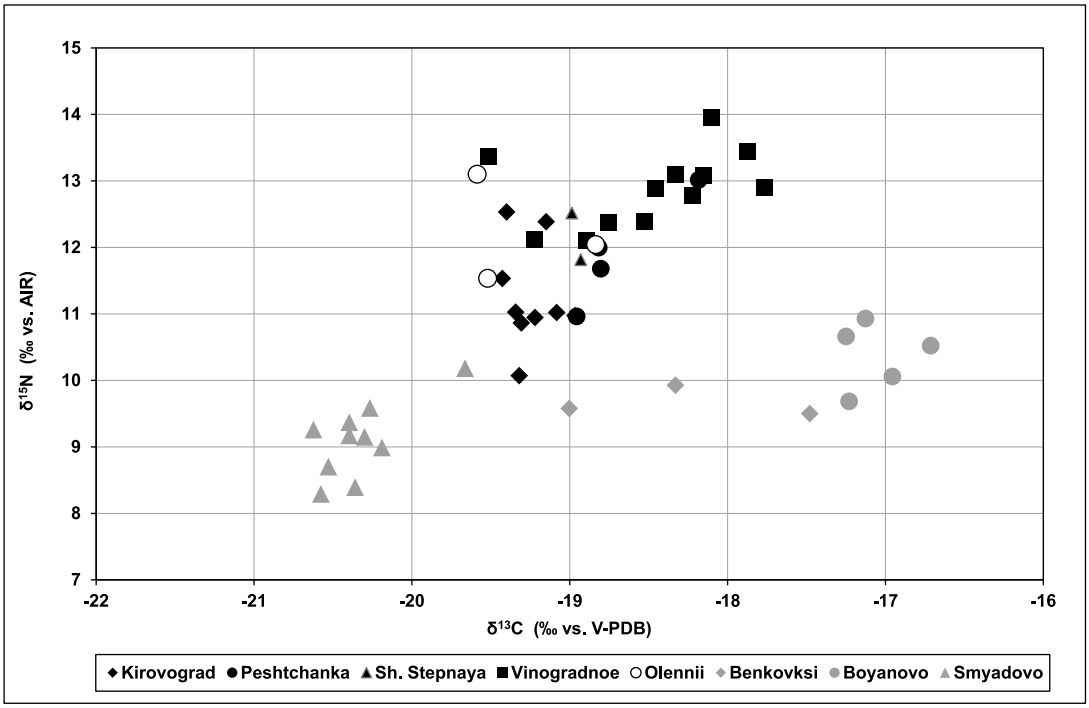
The results of the $\delta^{15}N$ analysis on human bones are shown in Figures 6.5 and Appendix D Table 1a. Overall, the samples from the three sites in the West Pontic together with the four sites in the North Pontic and the site in the Kuban region, yield $\delta^{15}N$ values between 9.26 and 13.95 ‰ and a mean of 11.18 ± 1.54 ‰ (1σ; n = 48), which is a relatively limited range considering the regional and chronological variation, including burials dating to the Eneolithic through to the Developed Catacomb culture. The West Pontic individuals exhibit a $\delta^{15}N$ average of 9.55 ± 0.74 ‰ (1σ; n = 18). Individually, a mean of 9.67 ± 0.23 ‰ (1σ; n = 3) and a limited range from 9.50 to 9.93 ‰ for the individuals from Benkovski, a mean of 10.37 ± 0.54 ‰ (1σ; n = 5) with a slightly wider range between 9.68 and 10.93 ‰ for those from Boyanovo and a mean value of 9.11 ± 0.56 ‰ (1σ; n = 10) with a span from 9.26 to 10.18 ‰ was obtained for the humans from Smyadovo. All the West Pontic sites yielded rather low $\delta^{15}N$ values and averages, whilst the North Pontic sites, on the other hand, produced higher $\delta^{15}N$ values with a mean of 12.14 ± 0.97 ‰ (1σ; n = 27). Individually, the human bone samples from Kirovograd yielded an average of 11.26 ± 0.78 ‰ (1σ; n = 9) with a range between 10.07 to 12.53 ‰, and the humans from Peshtchanka show a $\delta^{15}N$ mean of 11.91 ± 0.85 ‰ (1σ; n = 4) with a range from 10.96 to 13.02 ‰. The average $\delta^{15}N$ for Shakhta Stepnaya is 12.17 ± 0.49 ‰ (1σ; n = 2) with a range between 11.82 and 12.52 ‰ and 12.88 ± 0.56 ‰ (1σ; n = 12) with a range from 12.10 to 13.95 ‰ for Vinogradnoe. The three individuals from Olennii in the Kuban region yielded a mean of 12.23 ± 0.80 ‰ (1σ) with a range from 11.54 to 13.10 ‰.

It was shown that the data was normally distributed (Shapiro-Wilk test). Based on a test of homogeneity of variances the null hypothesis of the homogeneity of variances of the single sites was accepted at a 5% level of significance ($F = 0.80$, $p = 0.59$; Levene test). A one-way ANOVA revealed significant differences between the mean values of the sample sites ($F = 31.50$, $p < 0.001$). Statistically significant differences ($p = < 0.05$, Tukey's HSD post hoc test) were observed between Kirovograd and Vinogradnoe, Boyanovo and Smyadovo. Peshtshanka and Shakhta Stepnaya show significant differences to all West Pontic sites, Vinogradnoe is different to Kirovograd and the West Pontic sites. Olennii is different to the West Pontic sites. Benkovski is different to all sites except Kirovograd, Boyanovo and Smyadovo. Boyanovo is different to all sites except Benkovski and Smadovo. Smyadovo is different to all sites except Benkovski.

6.5.3.2 Results and discussion of combined $\delta^{13}C$ and $\delta^{15}N$ analysis of the human bones

West Pontic

Intra-regionally, the $\delta^{13}C$ and $\delta^{15}N$ results for the West Pontic sites are rather scattered with ranges of approximately 4 ‰ in $\delta^{13}C$ and 3 ‰ in $\delta^{15}N$ (Fig. 6.6, Appendix D Table 3). It is thus easy to distinguish between the three sites which have similar intra-site values but which are very diverse between sites. The West Pontic sites yielded average $\delta^{13}C$ and $\delta^{15}N$ values of –19.08 ± 1.54 ‰ (1σ) and 9.55 ± 0.74 ‰ (1σ)



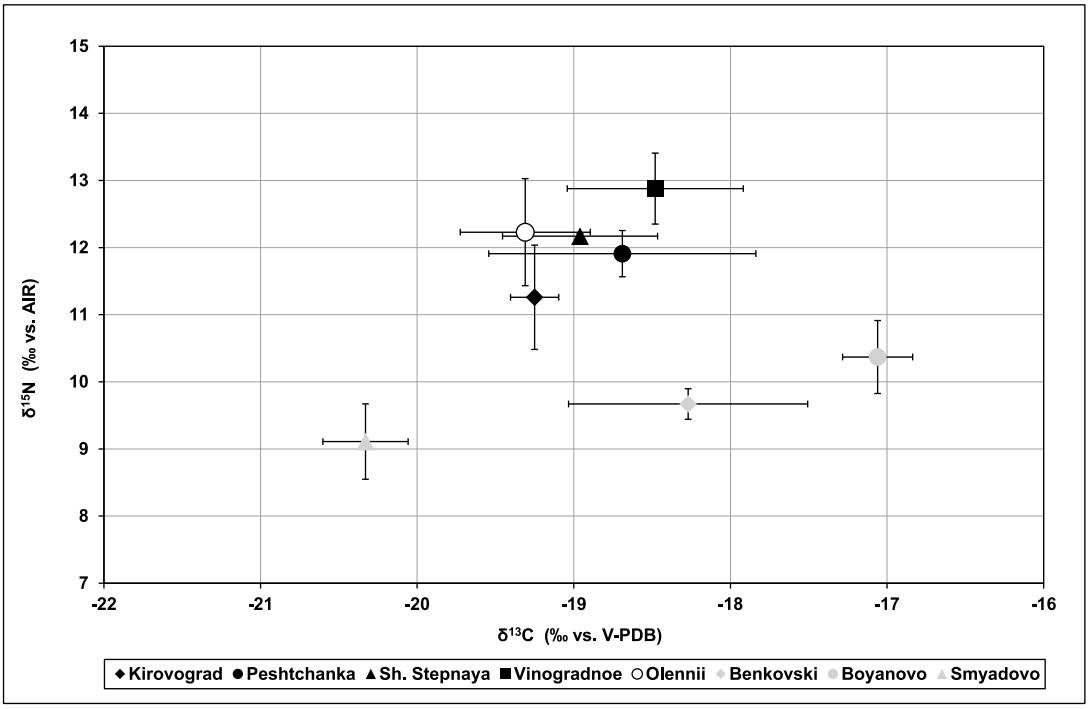


Fig. 6.6 | (a) Scatter plot of $\delta^{13}C$ and $\delta^{15}N$ data for four sites in the North Pontic (black symbols), Olennii in the Kuban (white symbols) and three sites in the West Pontic region (grey symbols).
(b) $\delta^{13}C$ and $\delta^{15}N$ averages and standard deviations for the sites mentioned.

respectively. The three individuals from Benkovski exhibited average $\delta^{13}C$ values of –18.27 ± 0.76 ‰ (1σ) and $\delta^{15}N$ values of 9.67 ± 0.23 ‰ (1σ), the five human bones from Boyanovo yielded $\delta^{13}C$ means of –17.06 ± 0.22 ‰ (1σ) and $\delta^{15}N$ means of 10.37 ± 0.54 ‰ (1σ), and the ten human individuals from Smyadovo gave $\delta^{13}C$ means of –20.33 ± 0.27 ‰ (1σ) and $\delta^{15}N$ means of 9.11 ± 0.56 ‰ (1σ). Intra-regional differences were revealed, when a one-way ANOVA was performed ($\delta^{15}N$: $F = 10.18$, $p = 0.002$; $\delta^{13}C$: $F = 140.55$, $p < 0.001$). Earlier, a Levene test showed that a homogeneity of variances cannot be rejected for both $\delta^{13}C$ and $\delta^{15}N$ distributions ($\delta^{15}N$: $F = 0.78$, $p = 0.48$; $\delta^{13}C$: $F = 3.15$, $p = 0.07$). While all three sites showed inter-site $\delta^{13}C$ differences that are statistically significant ($p < 0.05$, Tukey's HSD post hoc test), Smyadovo and Boyanovo also exhibit statistically significant differences in $\delta^{15}N$ values.

On an intra-site scale, the West Pontic sites Boyanovo and Smyadovo show little isotopic variation; however, at Benkovski, whilst the individuals exhibit little variation in $\delta^{15}N$ values, there is a considerably wider spread of carbon isotope ratios between individuals. The site-specific outliers from Benkovski are difficult to explain. The most depleted value in the Boyanovo cluster derives from the only Middle Bronze Age individual sampled. Despite very small differences, this might be seen as an indicator of Early and Middle Bronze Age dietary variations. Burial 18 is also a clear outlier amongst the otherwise homogeneous values obtained from samples from the Smyadovo cemetery. The isotope values from this burial are enriched in both carbon and nitrogen but still lie on the extended correlation line.

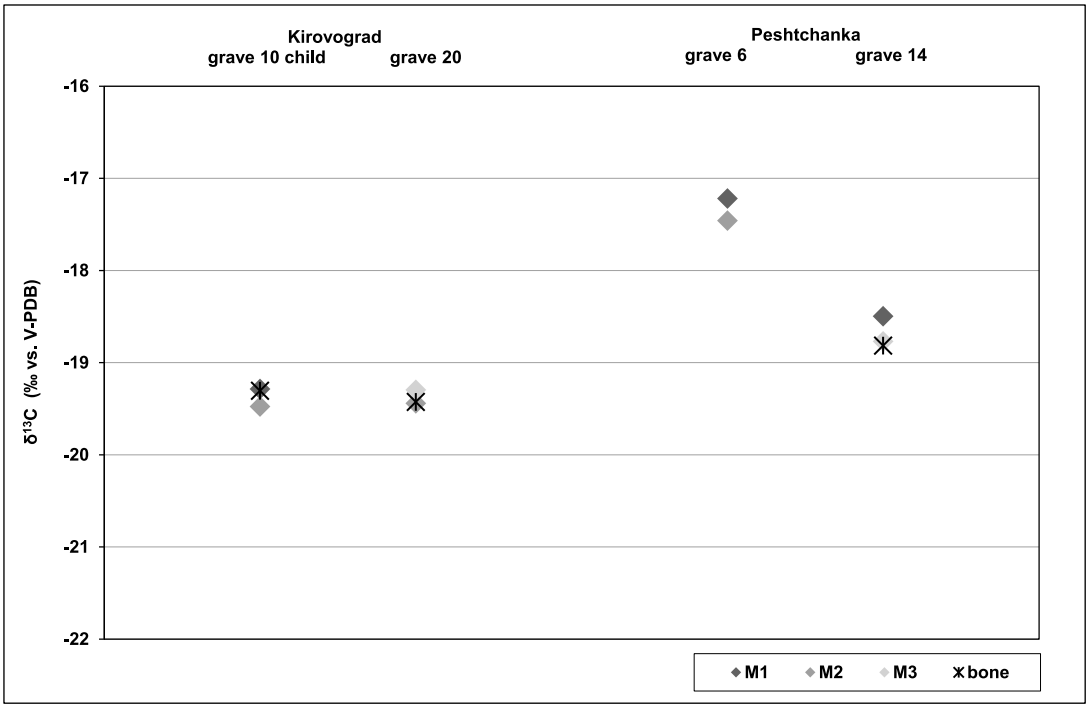
North Pontic

The $\delta^{13}C$ and $\delta^{15}N$ values from the four sites in the North Pontic region are tightly clustered, with ranges of approximately 2 ‰ for $\delta^{13}C$ and 4 ‰ for $\delta^{15}N$ (Fig. 6.6, Appendix D Table 3). The means of the combined North Pontic sites for $\delta^{13}C$ are –18.79 ± 0.51 ‰ and for $\delta^{15}N$ are 12.90 ± 0.97 ‰ (1σ, n = 27). Specifically, the averages are: $\delta^{13}C$ = –19.25 ± 0.15 ‰ and $\delta^{15}N$ = 11.30 ± 0.78 ‰ for Kirovograd (1σ, n = 9), $\delta^{13}C$ = –18.69 ± 0.34 ‰ and $\delta^{15}N$ = 11.91 ± 0.85 ‰ for Peshtchanka (1σ, n = 4), $\delta^{13}C$ = –18.96 ± 0.04 ‰ and $\delta^{15}N$ = 12.17 ± 0.49 ‰ for Shakhta Stepnaya (1σ, n = 2), and $\delta^{13}C$ = –18.48 ± 0.53 ‰ and $\delta^{15}N$ = 12.88 ± 0.56 ‰ for Vinogradnoe (1σ, n = 12). A Levene test showed that a homogeneity of variances must be rejected for $\delta^{13}C$ ($F = 3.61$, $p = 0.03$), while the null hypothesis cannot be rejected for $\delta^{15}N$ ($F = 0.66$, $p = 0.58$). Comparing the sites on a regional level, the $\delta^{13}C$ results vary with statistical significance ($p = 0.004$, Kruskal-Wallis non-parametric test, because the variances are heterogeneous), and the results also show significant differences in $\delta^{15}N$ ($F = 9.84$, $p < 0.001$, one-way ANOVA).

On an intra-site scale in the North Pontic, the humans from Kirovograd yielded consistent $\delta^{13}C$ values but more distributed $\delta^{15}N$ values with burial 16 being most depleted and burials 8 and 14 being most enriched in $\delta^{15}N$. The individual from grave 10 in Peshtchanka is isotopically more enriched than the three other humans. The two individuals from Shakhta Stepnaya yield similar isotopic values. The isotopic values for the humans from Vinogradnoe correlated well with the enriched isotope ratios of the Early Catacomb culture individuals from kurgan 24 grave 15 burial 2 (female adult) and kurgan 24 grave 34 burial 2 (male adult) at the top end. The only Eneolithic sample, kurgan 3, grave 15, can be regarded as an outlier due to the combination of low $\delta^{13}C$ and high $\delta^{15}N$ values. The $\delta^{13}C$ values of –19.31 ± 0.42 ‰ and $\delta^{15}N$ values of 12.23 ± 0.80 ‰ in the Olennii samples are more scattered (1σ, n = 3).

Inter-regional

On an inter-regional scale, Smyadovo yields the most depleted and Boyanovo the least depleted values in $\delta^{13}C$. The West Pontic results show considerable diversity in the $\delta^{13}C$ values obtained, whereas the North Pontic results cluster more closely. The results from Olennii are comparable to the North Pontic values.



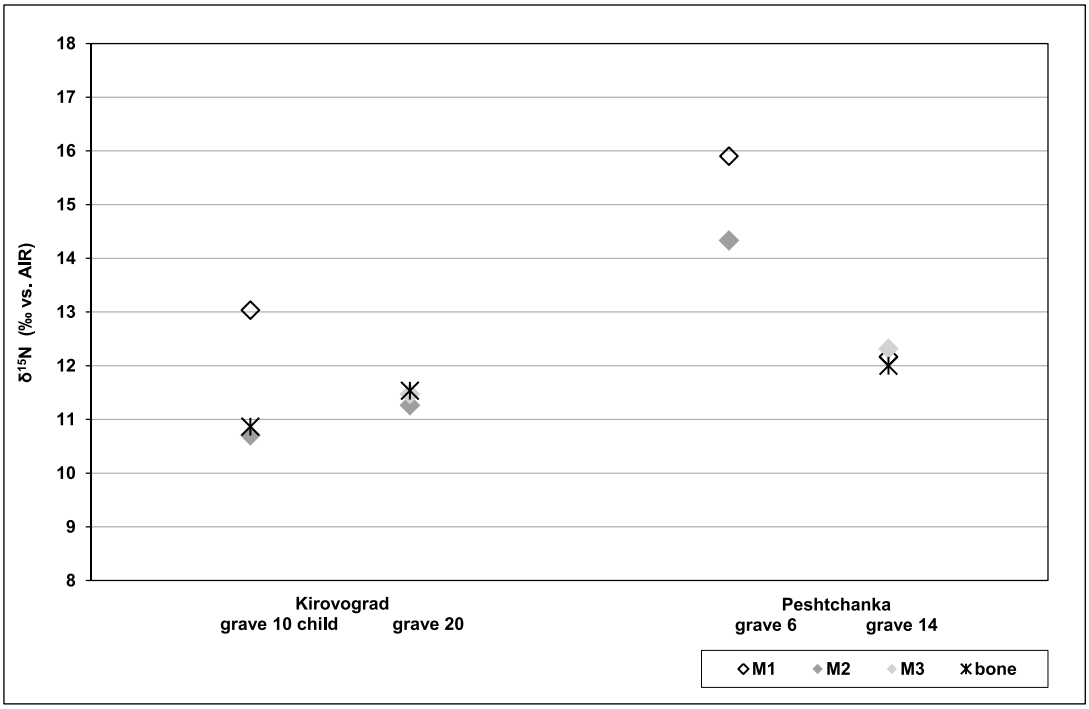


Fig. 6.7 | Scatter plots of $\delta^{13}C$ data (a) and $\delta^{15}N$ data (b) for the human tooth samples.

The null hypothesis that the regional means of West Pontic, North Pontic and Kuban region are equal cannot be rejected at a 5% level of significance ($F = 0.61$, $p = 0.55$; one-way ANOVA). The lowest $\delta^{15}N$ values come from the samples from Smyadovo, the highest values from the individuals from Vinogradnoe. In general, the human bones from the West Pontic exhibit more depleted values than those from the North Pontic region and from Olennii. Statistical differences can be observed between the West Pontic and the North Pontic/Kuban regions ($F = 43.94$, $p < 0.001$; one-way ANOVA). When the results from Benkovski and Boyanovo are excluded, there is a regressional relationship between $\delta^{13}C$ and $\delta^{15}N$values resulting in low $\delta^{15}N$ and $\delta^{13}C$ values in the West Pontic site of Smyadovo and high $\delta^{13}C$ and $\delta^{15}N$ values in the North Pontic.

6.5.3.3 Human teeth

In addition to the bones, eight teeth from the four individuals that were found to be most interesting from the Sr and O results were analysed for light stable isotope ratios (Fig. 6.7, Appendix D Table 1a). In contrast to bone, which reflects the last years or decades of life the nitrogen isotopic signal in teeth mirrors the diet during childhood.

In respect to $\delta^{13}C$, the eight teeth of four individuals yielded similar results to the bones of the same individuals. Only the human in kurgan 1 grave 14 in Peshtchanka yielded results that were less depleted than the bone $\delta^{13}C$ average of the site. The four teeth of the kurgan in Kirovograd showed a very limited range of $\delta^{13}C$ values between –19.48 and –19.29 ‰ and an average of –19.39 ± 0.10 ‰ (1σ). The four results for the teeth in Peshtchanka are slightly more scattered with a range from –18.77 to –17.22 ‰ and a mean of –17.99 ± 0.76 ‰ (1σ).

$\delta^{15}N$ signals in nursing children and their breastfeeding mothers are altered such that breastfed children are one trophic level above the mother. This affects the $\delta^{15}N$ values in the first and, at least partly, the second molars. The $\delta^{15}N$ average of the two individuals from the Kirovograd kurgan is 11.62 ± 0.10 ‰ (1σ) (n = 4) with a range from 10.70 to 13.03 ‰. The mean for Peshtchanka is 13.68 ± 1.78 ‰ (1σ) (n = 4) with a range from 12.17 to 15.90 ‰.

6.6 Discussion

6.6.1 Discussion of the results of the faunal references compared to further studies

It has been demonstrated in a number of studies (e.g. Ambrose/Norr, 1993) that there is significant isotopic variability within populations, which necessitates the analysis of a substantial number of different, preferably contemporaneous, animal species. In doing so, intra-site variations caused by environmental and climatic differences may also be detected (e.g. Hollund et al., 2010; Stevens et al., 2010).

In the present study three faunal bones from Kirovograd and one from Ovchartsi were available for analysis. In addition, two animal bones from Mayaki and Novozvanovka in the North Pontic region were sampled (Appendix D, Table 1b). The mean $\delta^{13}C$ value obtained from all faunal reference bones was –19.3 ± 0.8 ‰ and 7.3 ± 1.8 ‰ (1σ, n = 6). The low number of faunal reference data can be compared with, and supplemented by, other data collected in the same study regions (Table 6.1). There are several palaeodietary studies of material from the North Pontic and Caspian steppes, which include fau-

Table 6.1 | $\delta^{13}C$ and $\delta^{15}N$ values, means and standard deviations (if available) in faunal remains of comparable studies in the same study regions.

species	n	region	period	$\delta^{13}C$ (‰)	SD	$\delta^{15}N$ (‰)	SD	reference
Bos spec.	7	NE Bulgaria	Eneolithic	–19.6	0.3	6.1	0.5	Honch et al., 2006
Equus spec.	1	NE Bulgaria	Eneolithic	–20.1		5.1		Honch et al., 2006
Equus asinus hydruntius	4	NE Bulgaria	Eneolithic	–20.8	0.04	3.6	0.1	Honch et al., 2006
red deer (*Cervus elaphus*)	1	NE Bulgaria	Eneolithic	–20.1		5.3		Honch et al., 2006
Ovicaprid	5	NE Bulgaria	Eneolithic	–19.1	3	7.8	1.6	Honch et al., 2006
cattle (*Bos taurus*)	6	Ukraine	Eneolithic	–20.8	0.5	6.6	1	Iacumin et al., 2004b
cattle (*Bos taurus*)	8	Ukraine	Bronze Age	–19.39	0.46	7.18	0.73	Privat, 2004
horse (*Equus caballus*)	6	Ukraine	Eneolithic	–20.6	0.1	3.6	0.2	Iacumin et al., 2004b
horse (*Equus caballus*)	9	Ukraine	Bronze Age	–20.8	0.33	4.89	0.99	Privat, 2004
red deer (*Cervus elaphus*)	2	Ukraine	Bronze Age	–20.35	0.92	5.15	2.9	Privat, 2004
red deer (*Cervus elaphus*)	5	Ukraine	Eneolithic	–21.5	1	6.2	1.4	Iacumin et al., 2004b
sheep (*Ovis aries*)	25	Ukraine	Bronze Age	–19.62	0.59	7.02	1.07	Privat, 2004
Ovicaprid	9	Ukraine	Eneolithic	–20.6	0.8	5.8	0.6	Iacumin et al., 2004b
herbivore	n/a	Ukraine	Neolithic/ Eneolithic	–21.50	1.50	6.25	1.25	Lillie et al., 2012
herbivore	n/a	Ukraine (forest-steppe)	Bronze Age	–20.3	0.85	6.3	1.5	Privat, 2004
cattle	2	Southern Russia	Eneolithic	–19.85		7.7		Shishlina et al., 2009
sheep	1	Southern Russia	Eneolithic	–17.86		11.7		Shishlina et al., 2009
deer	2	Southern Russia	Maikop	–22.51		5.5		Shishlina et al., 2009
sheep	2	Southern Russia	Yamnaya	–21.2		9.5		Shishlina et al., 2009
sheep	4	Southern Russia	East Manych Catacomb	–18.2		8.9		Shishlina et al., 2009
sheep	5	Southern Russia	East Manych Catacomb	–18.51	0.88	7.24	1.77	van der Plicht et al., 2006
cattle	2	Southern Russia	East Manych Catacomb	–17.92		9.6		Shishlina et al., 2009
cattle	1	Southern Russia	Early Catacomb	–18.5		9.92		van der Plicht et al., 2006
horse	1	Southern Russia	East Manych Catacomb	–20.65		6.2		Shishlina et al., 2009
horse	1	Southern Russia	Early Catacomb	–21.16		4.66		van der Plicht et al., 2006
sheep	2	Southern Russia	Steppe North Caucasus	–18.39		12.2		Shishlina et al., 2009
herbivore	19	North Caucasus	Maikop	–18.1	1.5	8.8	1.9	Hollund et al., 2010

nal reference material. Larger data sets exist from Mesolithic to Eneolithic remains in the Dnieper Rapids region (Lillie/Richards, 2000; Lillie, 2003; Lillie et al., 2003; Lillie/Jacobs, 2006; Lillie et al., 2009; Lillie/Budd, 2011; Lillie et al., 2011; Lillie et al., 2012), Bronze and Iron Age sites in the North Pontic (Privat, 2004; Privat et al., 2007) and Bronze Age sites in the Caspian steppes (van der Plicht et al., 2006; Shishlina et al., 2007; Shishlina, 2008; Shishlina et al., 2009; Shishlina et al., 2012). The latter authors also worked on material from the North Caucasus piedmont, which together with sites in the Caucasus Mountains has been subject to further discussion in Hollund et al. (2010) and Higham et al. (2010).

$\delta^{13}C$ values that lie around –21 ‰ would be expected for Holocene herbivores of a purely terrestrial C_3 diet in a moderate climate (e.g. Dürrwächter et al., 2006, 43: –22.5 to –19.0 ‰ for inland continental Europe). Müldner and Richards (2007, 684) give typical values of –22 to –21.5 ‰ ($\delta^{13}C$) and 5 to 6 ‰ ($\delta^{15}N$) for Roman to Medieval terrestrial herbivores on the British Island feeding on C_3 plants. Hollund and colleagues (2010, table 1, 2978 fig. 5) found several per mil enriched carbon and nitrogen isotope values in the terrestrial herbivores in the North Caucasus with mean $\delta^{13}C$ and $\delta^{15}N$ values of –18.1 ± 1.5 ‰ and 8.8 ± 1.9 ‰ respectively (1σ, n = 14). Shishlina and colleagues (2012, 180, 183 fig. 3) were able to distinguish between two groups of animal stable isotope values (n = 62) from the Caspian steppes. Domesticated animals grazing predominantly on C_3 plants featured average values of $\delta^{13}C$ –20.7 ‰ and $\delta^{15}N$ 7.0 ‰, while animals on pastures with mixed C_3 and C_4 vegetation resulted in means of $\delta^{13}C$ –17.9 ‰ and $\delta^{15}N$ 12.4 ‰.

The average results of the faunal remains in this study lie between the results of the studies mentioned above. They are most comparable to the average values of sheep and cattle in the North Pontic during the Bronze Age, as published in Privat (2004) but also to the group 1 domesticated animals as in Shishlina et al. (2012, 180, 183 fig. 3). Therefore, the sheep or goat bones from grave 16 in Kirovograd, the animal bone from Ovchartsi and the cattle bone from Mayaki exhibit stable isotope values typical for an herbivorous diet that is primarily based on C_3 plants. The slightly less depleted $\delta^{13}C$ and the enriched $\delta^{15}N$ values compared to the continental studies are probably due to climatic differences, i.e. higher temperatures and aridity. Shishlina interpreted the enriched values of nitrogen in archaeological plant samples from the Caspian steppes as signals of stressed plants suffering from a lack of water (Shishlina et al., 2012, 184), which, in consequence leads to high stable isotopic values in animals. The sheep or goat bone from grave 15 in Kirovograd exhibits values of $\delta^{13}C$ –19.54 ‰ and $\delta^{15}N$ 10.58 ‰, the latter of which is > 3 ‰ more enriched than would be anticipated for an herbivore based upon the above comparative data. This might be explained by changing climatic conditions towards the developed Bronze Age or by misidentification of the animal species, because the enriched $\delta^{15}N$ value could hint to an omnivorous diet (but cf. the very high $\delta^{15}N$ values of some sheep in Hollund et al., 2010; Shishlina et al., 2012, 182). This data also agrees with values for the herbivores from southern Russia published by Iacumin et al. (2004b, 42–43 table 2). Based on a sample set of 20 animal bones (sheep, cattle, horse, deer) from three sites, the authors concluded that large variability in both carbon and nitrogen isotope values were related to seasonal movements, partly between areas of predominant C_3 plant growth and those of mixed C_3 and C_4 vegetation (Iacumin et al., 2004b, 40–43). The large distances between sites and differing climatic conditions are suggested as further reasons for the variable $\delta^{13}C$ (–21 to –16 ‰) and $\delta^{15}N$ (3 to 13 ‰) (Iacumin et al., 2004b, 46).

The data for herbivores from the Caspian steppes demonstrate comparable $\delta^{13}C$ values but exhibit more diverse and in some cases more enriched $\delta^{15}N$ values (Shishlina, 2008, appendix 2, tables 1–9). Ovicaprid bone from the North Caucasus dating to later periods show similar $\delta^{15}N$ values in association

with more depleted $\delta^{13}C$ values (Higham et al., 2010, 667 table 5), which can be explained by the small proportion of C_4 plants in the Caucasus vegetation due to the colder climate (Higham et al., 2010, 665). On the other hand, Hollund et al. (2010, 2979) measured rather high $\delta^{13}C$ and $\delta^{15}N$ values in terrestrial herbivores in the North Caucasus area. They explained the positive correlation between $\delta^{13}C$ and $\delta^{15}N$ values as being the result of climatic differences. Furthermore, these results are also comparable to terrestrial herbivore bone from the Dnieper Rapids region, although the data presented here is at the upper end of that range of isotopic values (Lillie et al., 2011, 63 fig. 2; Lillie et al., 2012, 87 fig. 3). The data presented here is more enriched compared to *Bos taurus* from the same region published by O'Connell (et al., 2003), for faunal remains from Molukhov Bugor and Semyenovka dating to the Neolithic-Eneolithic, and from Desyatiny, dating to the Early Bronze Age, with values that range from –21.8 to –19 ‰ for $\delta^{13}C$ and from 2.9 to 6.5 ‰ for $\delta^{15}N$ respectively (O'Connell et al., 2003, 254, table 16.1). The studies of Honch et al. (2006) on the Neolithic and Eneolithic sites Durankulak and Varna I and studies on the Mesolithic-Neolithic diet in the Danube Gorges region (e.g. Bonsall et al., 2000; Borić et al., 2004; Nehlich et al., 2010) provide reference data for comparison with the West Pontic region. Honch et al. (2006) found the mean $\delta^{15}N$ values of herbivorous species (n = 18) fell between 3.6 and 6.4 ‰ and those of omnivorous and carnivorous animals fell between 8 ‰ to 10 ‰ (Honch et al., 2006, 1496–1497). The unusually elevated $\delta^{15}N$ values observed in the ovicaprids in this study, with a mean that was some 2 ‰ more enriched than other herbivores, led to this group being excluded from the herbivorous mean $\delta^{15}N$ value. Several studies were conducted on the diet of the Mesolithic-Neolithic transition along the Danube Gorges and a large number of faunal bones were analysed for stable $\delta^{13}C$ and $\delta^{15}N$ ratios. Herbivore $\delta^{13}C$ and $\delta^{15}N$ values had means of ~ –22 ‰ and < 7 ‰, agreeing with the values expected for terrestrial C_3 herbivores (Borić et al., 2004, 224 table 1; Nehlich et al., 2010, 1136 table 3).

As shown in Figure 6.8, the data for the faunal reference material in this study is comparable to the results of other studies of fauna from the same regions. While the $\delta^{13}C$ means of these studies (–19.94 ‰ in Bulgaria, –20.54 ‰ in Ukraine and –19.4 ‰ in south Russia) are not significantly different, the $\delta^{15}N$ mean values of the fauna in Bulgaria (5.58 ‰) and in Ukraine (5.8 ‰) are more than 3 ‰ more depleted than the animals in south Russia (8.9 ‰). Since this enrichment is primarily observed in sheep, there is reason to suggest that elevated temperatures, grass type and aridity lead to enriched $\delta^{15}N$ values in herbivores and subsequently also in their consumers. On this basis, consumers of terrestrial herbivores in the study area are consequently expected to show stable isotope average values around –19.5 to –18 ‰ for carbon, and between 8 and 11 ‰ for nitrogen in Bulgaria and Ukraine, with $\delta^{15}N$ values of between 12 and 14 ‰ in south Russia.

6.6.2 Discussion of the results of the human bones

6.6.2.1 Internal site variation

The variation of $\delta^{15}N$ and $\delta^{13}C$ values between individuals within a site indicates whether the diets of those individuals were broadly similar or not. In a human or faunal population of the same period and region, the average standard deviation in $\delta^{15}N$ is approximately ± 1 ‰ (Iacumin et al., 2004b, 40). According to Hedges and Reynard (2007, 1242), however, intra-site variability can be up to 2 ‰, even when ignoring obvious outliers.

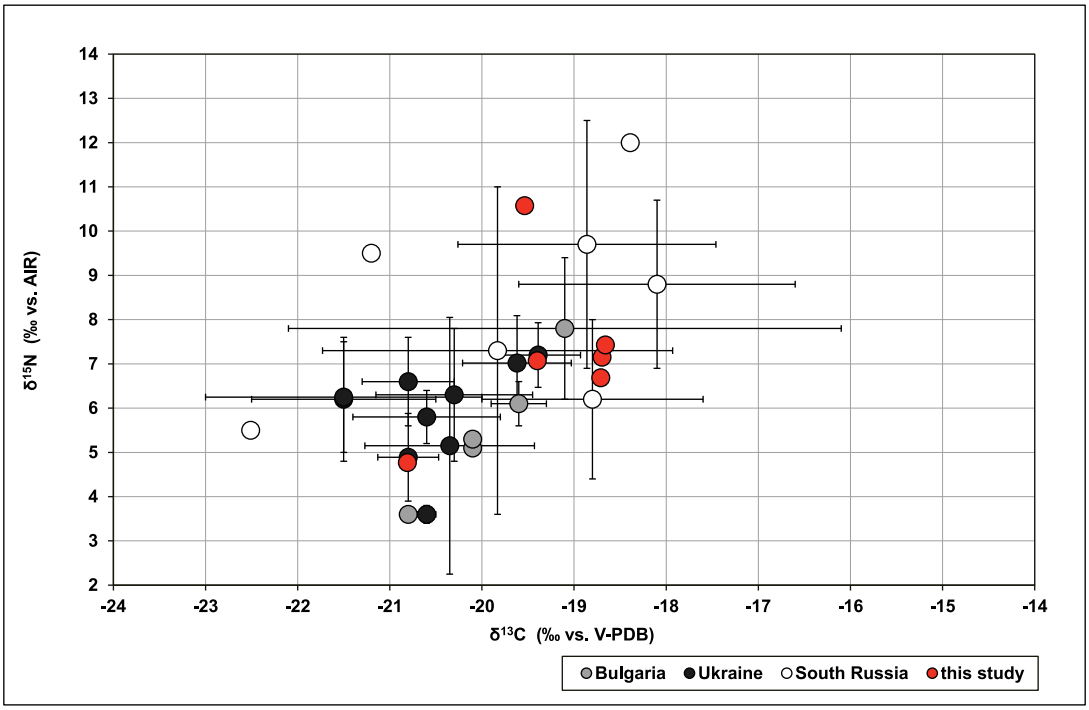


Fig. 6.8 | $\delta^{13}C$ and $\delta^{15}N$ values, means and standard deviations for the faunal remains in this study. By means of comparison data for animals in comparable studies are included.

When interpreting the diet of individuals buried in one kurgan, the interpretation is even more complicated. These individuals did not necessarily form one community, but are nevertheless believed to have lived in approximately the same geographical area and therefore to have had access to similar dietary resources. While intra-site variation might be caused by varying dietary components, chronological or anthropological factors may also be invoked to explain this variability. For example, seasonal mobility or migration to a place with a different climate and vegetation could explain diversity in stable isotope values of collagen (Hollund et al., 2010, 2972). On the other hand, where little variation is found, this can be explained by similar diets. Reitsema interpreted a $\delta^{13}C$ range of 1.4 ‰ and $\delta^{15}N$ range of 2.4 ‰ in Poland as not being highly variable (Reitsema et al., 2010, 1418).

The $\delta^{13}C$ and $\delta^{15}N$ averages, including standard deviations and ranges, are presented in Appendix D Table 3. The intra-site $\delta^{13}C$ ranges for the North Pontic sites are between 0.06 ‰ (Shakhta Stepnaya) and 1.75 ‰ (Vinogradnoe), and for the West Pontic between 0.54 ‰ (Boyanovo) and 1.52 ‰ (Benkovski). The $\delta^{13}C$ intra-site variability is rather limited, since the standard deviations reach between 0.04 and 0.76 and only the intra-site ranges of Vinogradnoe and Benkovski are above 1.5 ‰.

The intra-site $\delta^{15}N$ ranges are from 0.7 ‰ (Shakhta Stepnaya) to 2.46 ‰ (Vinogradnoe) in the North Pontic and from 0.43 ‰ (Benkovski) to 1.89 ‰ (Smyadovo) in the West Pontic. Due to small intra-site standard variations between 0.23 and 0.56 and limited $\delta^{15}N$ ranges the $\delta^{15}N$ intra-site variations can be regarded as low. The estimated trophic level shifts of 1 ‰ ($\delta^{13}C$) and 3 to 5 ‰ ($\delta^{15}N$) are only exceeded by the $\delta^{13}C$ variability in Vinogradnoe (1.75 ‰) and Benkovski (1.52 ‰). Consequently, on the basis of limited variability in both isotopic systems, similar protein sources for the individuals from each site is suggested, while intra-regionally the North and West Pontic region are more variable.

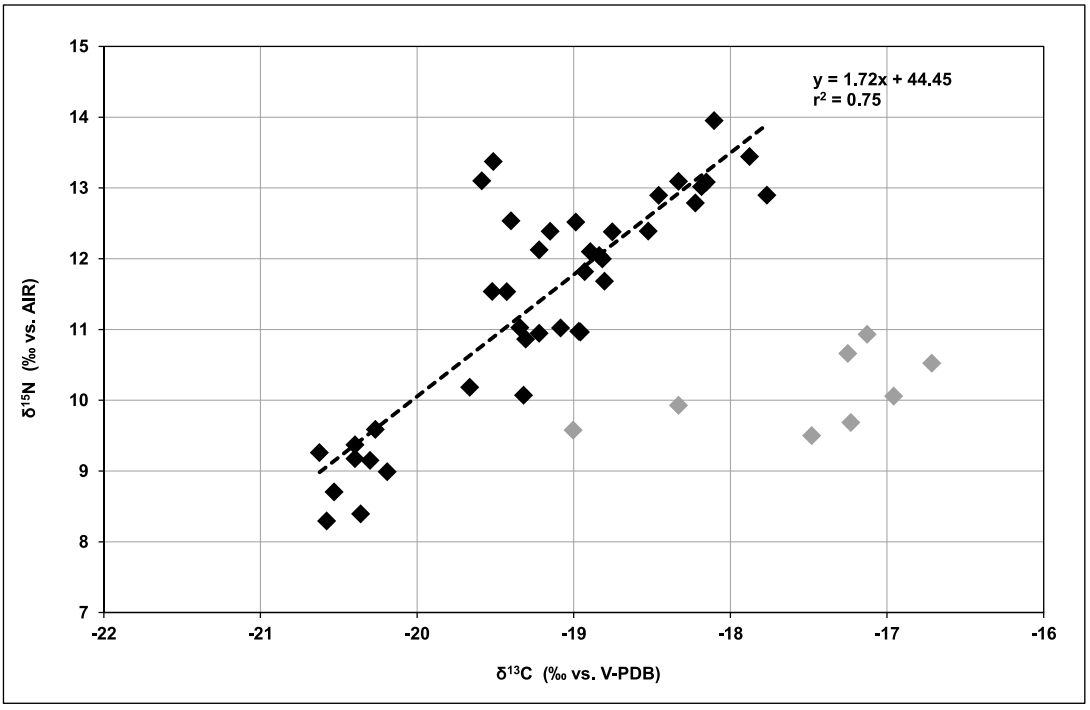


Fig. 6.9 | $\delta^{13}C$ and $\delta^{15}N$ values of the North Pontic sites, Smyadovo and Olennii (black diamonds) with a linear regression line. The results from Benkovski and Boyanovo (grey diamonds) were not included in the calculation.

Large intra-site $\delta^{13}C$ and $\delta^{15}N$ ranges either indicate diets based on different sources or that individuals come from different environments. Due to the fact that individuals sampled at the sites with wide $\delta^{13}C$ and $\delta^{15}N$ ranges and standard deviations (with the exception of Benkovski) date to different chronological periods, it cannot not necessarily be concluded that these communities lived on multiple food resources, as it could also be that they lived in different environments or that they belonged to more than one community occupying the same area, but which had significantly different diets.

There is a very weak to no correlation between both $\delta^{13}C$ and $\delta^{15}N$ standard deviations and sample sizes from each site ($r^2 = 0.004$; $r^2 = 0.014$) but a medium correlation between the $\delta^{13}C$ and $\delta^{15}N$ ranges and the sample sizes per site ($r^2 = 0.20$; $r^2 = 0.42$), which suggests that the ability to recognise differences in diet may also depend on the number of analysed samples.

6.6.2.2 Correlation between $\delta^{13}C$ and $\delta^{15}N$ ratios

There is a correlation between carbon and nitrogen isotope ratios evident in several studies (e.g. Honch et al., 2006). This may be due to environmental factors, i.e. reflecting a correlation in the plants, or it may be dietary, i.e. a two-end member diet (Iacumin et al., 2004b, 41; Hollund et al., 2010, 2981). For southern African mammals, for example, Lee-Thorp et al. (1993, 111) found a correlation between the uptake of C_4 plants and humidity. The C_4 grasslands are located in regions with predominantly more moisture than C_3 plants; therefore an inverse relationship between enriched $\delta^{15}N$ values and depleted $\delta^{13}C$ values was observed. Linear relationships at ratios of approximately 2 ($\delta^{15}N$) to 1 ($\delta^{13}C$) were ident-

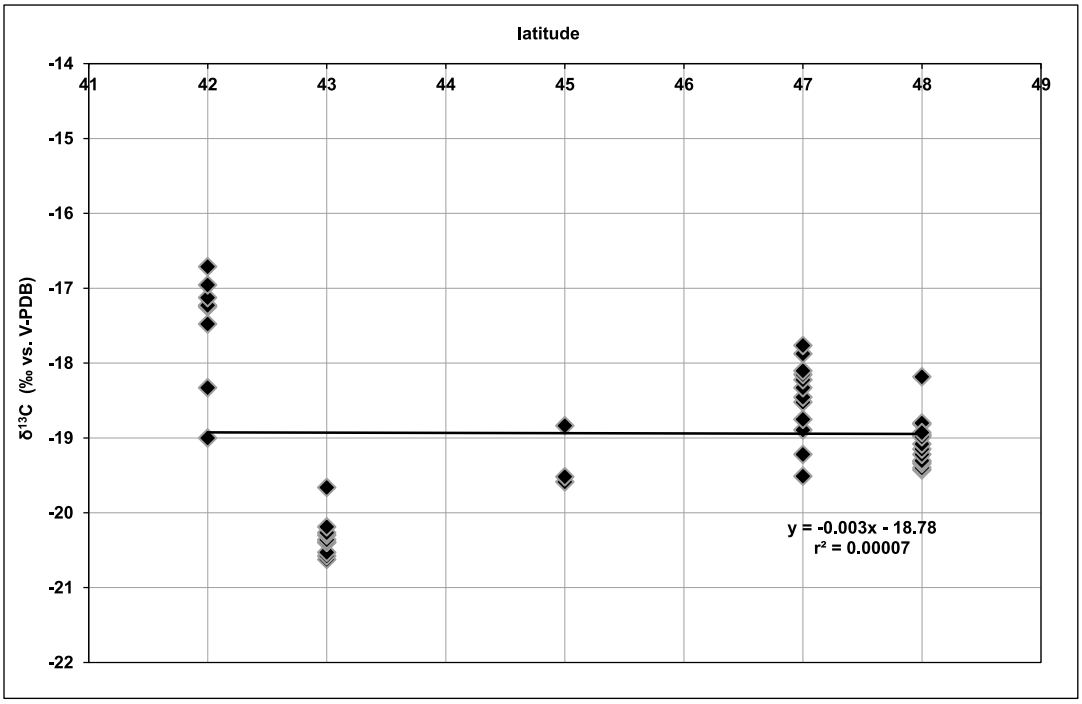
Table 6.2 | Site-internal and intra-regional linear regression equations.

site	y	r^2
Benkovski	–0.07x + 8.39	0.05
Boyanovo	0.23x + 14.21	0.01
Smyadovo	1.46x + 38.70	0.50
West Pontic	0.37x + 16.70	0.61
Kirovograd	–0.69x – 1.92	0.02
Peshtchanka	2.32x + 55.31	0.88
Shakhta Stepnaya	(only 2 data points)	
Vinogradnoe	0.44x + 21.05	0.17
North Pontic	1.23x + 35.27	0.42
Olennii	–0.53x + 1.94	0.08

ified between Neolithic farmers and Mesolithic populations. This linear trend was interpreted as a correlation of a diet with two end members: C_3 terrestrial food and marine resources (Richards/Hedges, 1999). Another example is the cemetery of Varna, where a linear trend with $\delta^{13}C$ and $\delta^{15}N$ gradients of approximately 1 to 1 was detected (Honch et al., 2006).

In steppe environments, C_4 plants are associated with more arid environments; hence an inverse correlation between enriched $\delta^{15}N$ and enriched $\delta^{13}C$ values would be expected. There is, in fact, a strong correlation between depleted $\delta^{13}C$ and $\delta^{15}N$ values, on the one hand, and enriched $\delta^{13}C$ and $\delta^{15}N$ values, on the other hand, which is on an inter-regional scale, ranging from Smyadovo via Kirovograd, Peshtchanka and Shakhta Stepnaya to Vinogradnoe (Fig. 6.9, Table 6.2). This can probably be explained by environmental differences between the sites rather than a two-end member diet. There is no such correlation between the Bulgarian sites. On an intra-site level, a strong correlation can be observed for the results from Peshtchanka ($r^2 = 0.88$), which is not explained by chronological differences between Eneolithic and Yamnaya individuals in fact hint at differing diets and hence maybe varying environments.

Figure 6.10 shows the linear regression lines between $\delta^{13}C$ and $\delta^{15}N$ values and latitude (a) and between those values and longitude (b). There is no coherent relationship between $\delta^{13}C$ and latitude or longitude, but there is a medium correlation between $\delta^{15}N$ values and latitude (linear regression analysis, $r^2= 0.60$). A strong correlation can be observed between $\delta^{15}N$ and longitude (linear regression analysis, $r^2 = 0.70$). It is suggested that this correlation is due to climatic shifts towards the east of the study region. Benkovski and Boyanovo do not agree with this regression line and would match a longitude of 30° instead, although the majority of the results from Smyadovo are more depleted and do not exactly agree with the trend line. The same is true for Olennii. A similar trend can be observed between $\delta^{15}N$ values and latitude. The results of Benkovski, Boyanovo, Olennii and Vinogradnoe cluster above the line, while the values from Smyadovo and Vinogradnoe are more depleted in $\delta^{15}N$. Nevertheless, there is a clear link between $\delta^{15}N$ value and the geographical location of the sites.



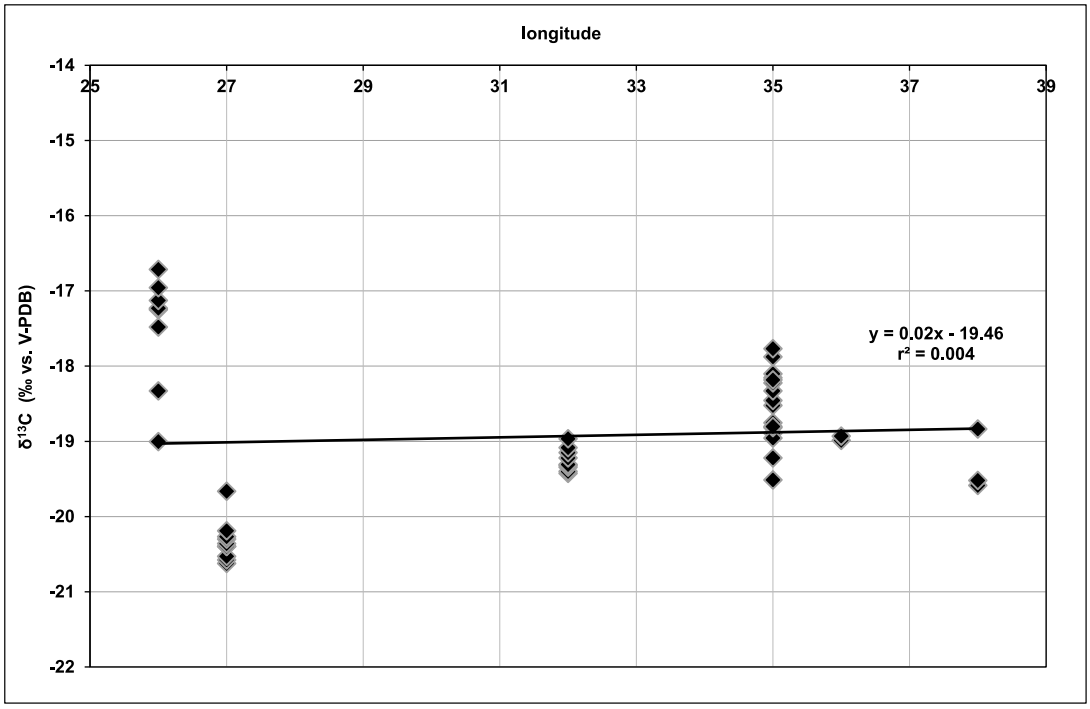


Fig. 6.10 | $\delta^{13}C$ and $\delta^{15}N$ data for the sites sampled distinguished by and plotted against geographic location (latitude [a] and longitude [b]).

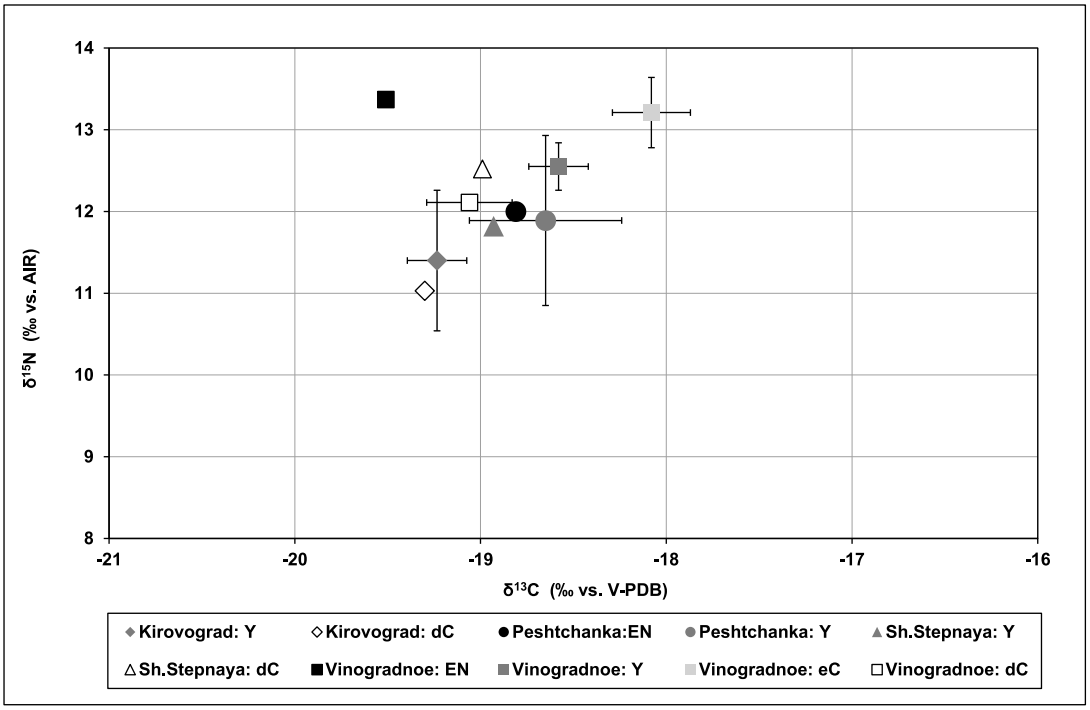


Fig. 6.11 | Average $\delta^{13}C$ and $\delta^{15}N$ with standard deviations for the different cultures in the North Pontic: EN = Eneolithic,Y = Yamnaya, eC = early Catacomb, dC= developed Catacomb.

6.6.2.3 Chronological comparison

There are no clear chronological trends between the Eneolithic, Yamnaya period and the Early and Developed Catacomb culture periods in the samples of the North Pontic sites (Fig. 6.11, Appendix D Table 4), but due to small group sizes, assertions are difficult to make. On average, humans of the Developed Catacomb culture are marginally more depleted in $\delta^{13}C$ than the Yamnaya individuals. Intra-site variations, however, are more visible than chronological differences. At Vinogradnoe, the only site where it was possible to take samples from all chronological periods, small but significant chronological differences are evident. A homogeneous distribution of the chronological groups in Vinogradnoe cannot be rejected on a 5% level of significance for both $\delta^{13}C$ ($F = 0.25$, $p = 0.78$) and $\delta^{15}N$ ($F = 4.02$, $p = 0.06$; Levene test). A test of differences of the mean $\delta^{13}C$ and $\delta^{15}N$ values (one-way ANOVA) was performed to reveal differences between the chronological groups. The null hypothesis that the mean values of the chronological groups are homogeneous can be rejected on a 5% level of significance ($\delta^{13}C$: $F = 23.87$, $p < 0.001$; $\delta^{15}N$: $F = 9.17$, $p = 0.01$). When all North Pontic samples are considered together, a one-way ANOVA can only be performed for $\delta^{13}C$ ($F = 18.22$, $p = < 0.001$), because a test of homogeneity of variances was negative regarding $\delta^{15}N$ ($F = 4.27$, $p = 0.02$; $\delta^{13}C$: $F = 0.53$, $p = 0.67$; Levene test). A Kruskal-Wallis test was performed and it could be shown that chronological groups also differ significantly in respect to $\delta^{15}N$ ($p = 0.003$).

Results from this site did not show a distinct chronological trend. Privat identified an increase in both $\delta^{13}C$ and $\delta^{15}N$ at Ukrainian sites from the Bronze Age to the Iron Age. Further diachronic isotope

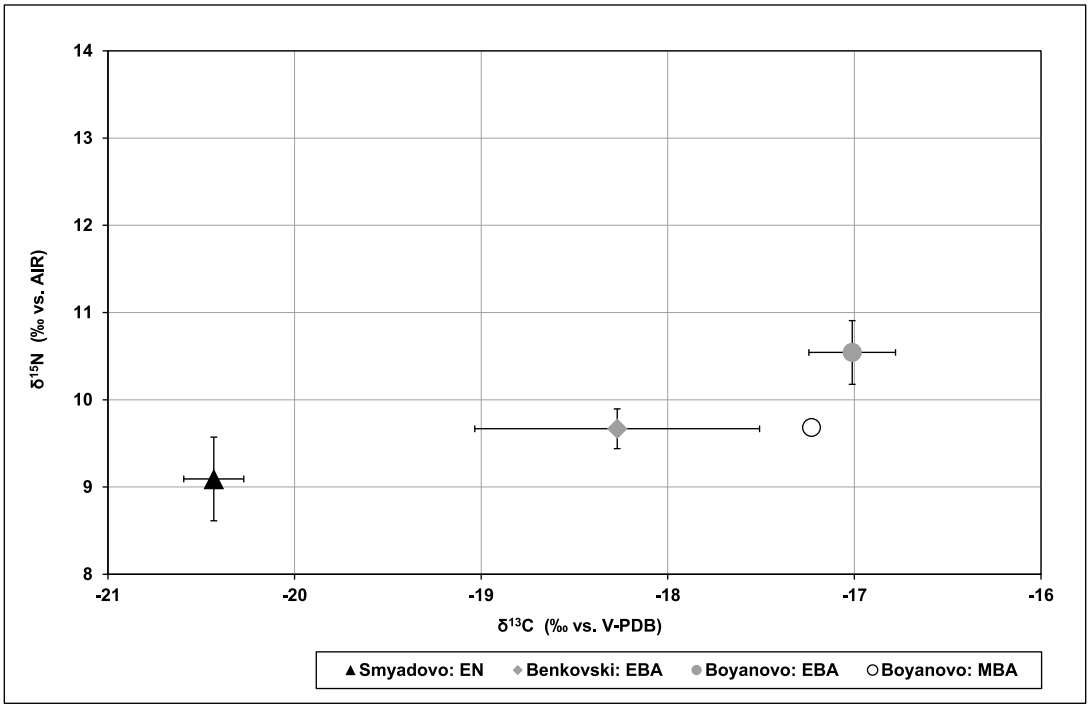


Fig. 6.12 | Average $\delta^{13}C$ and $\delta^{15}N$ with standard deviations for the different time periods in the West Pontic: EN = Eneolithic, EBA = Early Bronze Age, MBA = Middle Bronze Age.

studies in the West Eurasian steppes for the Mesolithic through to the Iron Age demonstrated that there are very small chronological variations in human and animal diet (O'Connell et al., 2003, 261).

In the West Pontic, Boyanovo is the only site that gave results for individuals from different time periods (Fig. 6.12, Appendix D Table 4). The single Middle Bronze Age individual from Boyanovo is depleted in $\delta^{15}N$ and slightly more negative in $\delta^{13}C$ than the Early Bronze Age individuals from the same site. The variations in results from the Eneolithic samples from Smyadovo compared with the other two Bulgarian sites may either be chronologically or site-related.

6.6.2.4 Variations based on gender and age

In controlled feeding experiments on animals it has been shown that there are no significant differences between female and male individuals that consume the same diet (DeNiro/Schoeninger, 1983). Hence, differences in $\delta^{13}C$ and $\delta^{15}N$ values between male and female individuals of the same archaeological population would be expected to be caused by differing diets or other factors like pregnancy and breast-feeding. Occasionally, isotopic variations have been linked to dietary differences between the genders. In Dereivka, for example, elevated $\delta^{15}N$ values in females compared with those in males were interpreted as arising from greater freshwater fish consumption among women (Lillie/Richards, 2000, 968). Dietary differences in medieval Giecz, Poland, were suggested to depend on inequalities in meat consumption between the genders (Reitsema et al., 2010, 1420–1421). In Durankulak, on the other hand, no differences in $\delta^{13}C$ and $\delta^{15}N$ values were observed between females and males (Honch et al., 2006, 1502).

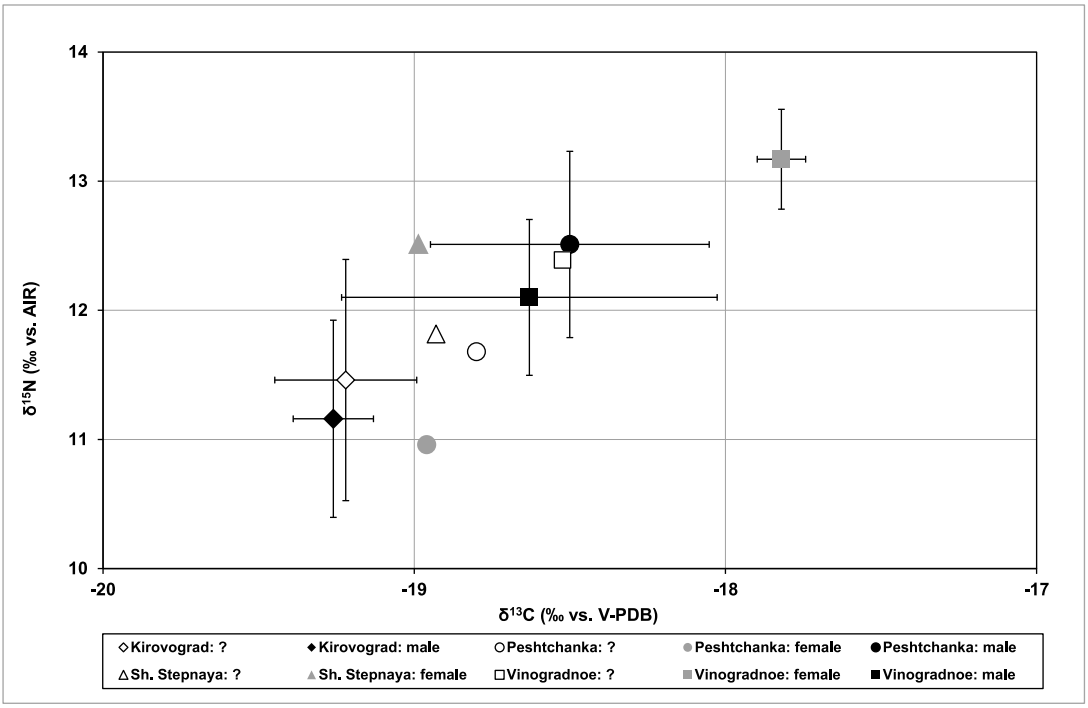


Fig. 6.13 | Average $\delta^{13}C$ and $\delta^{15}N$ for males (black), females (grey) and individuals of undetermined sex (white).

In the present study, analysis of potential gender based differences in $\delta^{13}C$ and $\delta^{15}N$ values is problematic because of the very small sample sizes and because of the large number of males sampled, compared to females and infants. Furthermore, variations based on gender are often correlated with chronological differences. Only the sites in the North Pontic were investigated in this respect (Fig. 6.13, Appendix D Table 5), since the West Pontic humans have not yet been entirely sex-assigned and were therefore excluded. In Kirovograd, the individuals of undetermined sex (n = 3) and the males (n = 6) correspond in $\delta^{13}C$ and $\delta^{15}N$ averages. The two males in Peshtchanka are elevated in $\delta^{15}N$ and less depleted in $\delta^{13}C$ compared to the female and the infant, which might be an indicator for a diet with a higher proportion of meat or fish. The female in Shakhta Stepnaya has a slightly more enriched $\delta^{15}N$ value than the mature individual of undetermined sex but they have similar $\delta^{13}C$ ratios. Differences between males and females in Vinogradnoe are statistically not significant ($\delta^{15}N$: Z = 0.71, p = 0.69; $\delta^{13}C$: Z = 1.28, p = 0.76; Kolmogorov-Smirnov test). The two female individuals in Vinogradnoe, however, seem very different and yield enriched $\delta^{13}C$ and $\delta^{15}N$ values, which again could indicatea diet richer in protein, presumably deriving from animals. The variations could also have chronological cause, as the values of the Early Catacomb culture males (n = 4) correlate with those of the two females. There are no statistically significant differences between males and individuals of undetermined sex in Kirovograd ($\delta^{15}N$: Z = 0.47, p = 0.98; $\delta^{13}C$: Z = 0.47, p = 0.98; Kolmogorov-Smirnov test).

No statistically significant variations based on gender are proven for the North Pontic region in total ($\delta^{15}N$: F = 0.69, p = 0.51; $\delta^{13}C$: F = 1.80, p = 0.19; one-way ANOVA) and a general trend of sex-based differences cannot be recorded.

It has been shown that isotopic values of various age groups do not depend on physiological distinctions (Prowse et al., 2005, 2). Overall, intra-site variations are greater than those based on age. $\delta^{15}N$

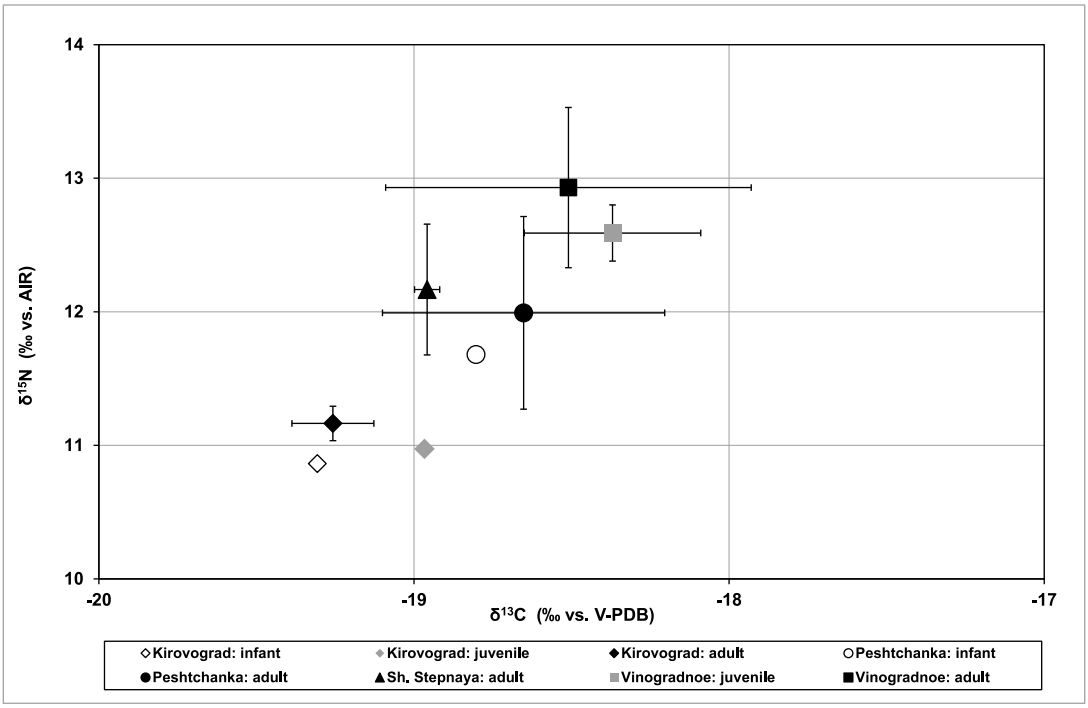


Fig. 6.14 | Average $\delta^{13}C$ and $\delta^{15}N$ for infants (white), juveniles (grey) and adults (*adultus* and *maturus*, black).

values of the adult individuals from Kirovograd, Peshtchanka and Vinogradnoe are marginally enriched compared to the infants from the same sites (Fig. 6.14, Appendix D Table 6). The differences between the juvenile and adult individuals from Vinogradnoe were statistically not significant ($\delta^{15}N$: Z = 0.78, p = 0.59; $\delta^{13}C$: Z = 0.65, p = 0.80; Kolmogorov-Smirnov test). Minor variations between children and adults might suggest a diet containing a higher proportion of fish or meat during adulthood. When the age groups of all samples are considered, a test of homogeneity of variances cannot be rejected ($\delta^{15}N$: p = 0.63, $\delta^{13}C$: p = 0.64; Levene test). Therefore, a one way-ANOVA was performed ($\delta^{15}N$: F = 0.45, p = 0.72; $\delta^{13}C$: F = 0.88, p = 0.46) and showed that the null hypothesis (the means of the age groups are equal) cannot be rejected. Hence, there are no statistically significant differences based on age.

6.6.3 Discussion of the results of $\delta^{13}C$ and $\delta^{15}N$ analysis on teeth

The $\delta^{13}C$ and $\delta^{15}N$ results for the four individuals from Kirovograd and Peshtchanka are rather consistent (Fig. 6.15). The $\delta^{13}C$ values of teeth and bone are similar for each individual sampled. This is also true for the $\delta^{15}N$ values of Kirovograd burial 20 and Peshtchanka burial 6. Only the $\delta^{15}N$ values from the first molars of burial 10 child in Kirovograd and burial 14 in Peshtchanka are significantly elevated compared to the second molars and the bone. The second molar of Peshtchanka burial 14 also yielded a $\delta^{15}N$ ratio above the site average, derived predominantly from the analysis of bone. This suggests that the first molars and possibly the second molar of Peshtchanka burial 14 are showing the influence of trophic level enrichment from breastfeeding, which can enrich $\delta^{15}N$ values by up to 3 ‰ as discussed above. The first molar of Peshtchanka burial 6, in contrast, matches the $\delta^{15}N$ values of the third molar and the bone. Fur-

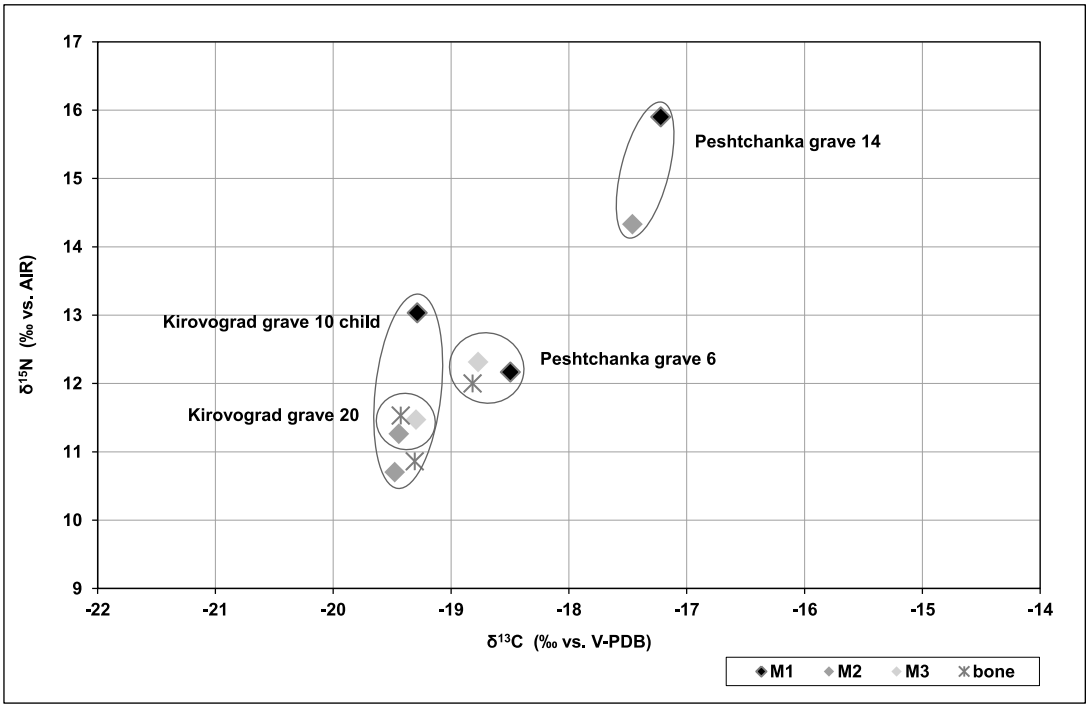


Fig. 6.15 | $\delta^{13}C$ and $\delta^{15}N$ data for teeth (first, second and third molars) and bones from the burials 1.10 child and 1.20 in Kirovograd and 1.6 and 1.14 in Peshtchanka.

thermore, the data suggests that the individuals in Kirovograd grave 20 and Peshtchanka grave 6 did not undergo significant changes in the sources of dietary protein during life, since isotope values derived from the bones, representing the last period of life, do not differ significantly from those values derived from the teeth. The nitrogen isotope signals of the infant (*Infans* I) bones from burials 25b and 35a in Olennii give both the lowest and the highest values from the site, but due as the sample size was only three, this cannot be meaningfully interpreted.

The results suggest that there were different feeding strategies, where some infants were breastfed (Peshtchanka burial 14, Kirovograd burial 10), while others were not (Peshtchanka burial 6, Kirovograd burial 20). Both individuals from Peshtchanka date to the Eneolithic period, while both sampled individuals from Kirovograd can be linked to the Yamnaya culture. Interestingly, burial 14 is an outlier not only in $\delta^{13}C$ and $\delta^{15}N$ values but also in $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values.

6.6.4 Discussion of possible dietary components

In predominantly pastoralist populations, enrichment in $\delta^{15}N$ due to the consumption of primary or secondary animal products, i.e. meat or milk would be expected. Using the example of the Masai in East Africa, Hedges and Reynard (2007, 1248) explain the relatively elevated $\delta^{15}N$ values by the high contribution of animal products to the diet. $\delta^{15}N$ values do not differentiate between meat and milk, the latter being a likely dietary component based on comparison with other pastoralist societies. Lower $\delta^{15}N$ values indicate a larger proportion of plant-derived foods in the diet as may be expected in agrarian

societies. Dürrwächter et al. (2006, tables 2, 3) found that $\delta^{13}C$ values of Middle Neolithic humans in Trebur, Southern Germany, ranged from –20.6 to –19.2 ‰ with $\delta^{15}N$ values ranging from 8.4 to 10.7 ‰, while humans from the *Linearbandkeramik* site of Herxheim showed $\delta^{13}C$ ranges between –20.5 and –19.6 ‰ and $\delta^{15}N$ ranges between 7.8 and 12.1 ‰. Similar results were published by Nehlich et al. (2009) for the *Linearbandkeramik* site of Nieder-Mörlen, where the $\delta^{13}C$ values ranged between –21 and –19.4 ‰ and the $\delta^{15}N$ ranged between 8.7 and 12.8 ‰. The 12 individuals exhibited slightly wider distributed $\delta^{15}N$ values than those in southern Germany. While in that study the $\delta^{13}C$ values are on average slightly more depleted and ranges more limited, the $\delta^{15}N$ values and ranges are comparable to the Bulgarian results. The $\delta^{15}N$ values are higher, which could be the result of a diet richer in protein or possibly because of significant alteration in $\delta^{15}N$ caused by changes in climatic conditions (Heaton et al., 1986).

To estimate the contribution of vegetable, cereal and plant intake in addition to meat consumption, palaeobotanical analyses of the excavated sites would be extremely helpful. In general, C_3 plants were much more common in Holocene continental Europe than C_4 plants, and are therefore likely to have been the predominant vegetation type in the study areas (e.g. Shishlina, 2008; Shishlina et al., 2012, 184). C_4 vegetation in the west Eurasian steppes is more or less absent at latitudes above 50° and declines from south to north (Iacumin et al., 2004b, 41 citing Пьянков/Мокроносов, 1993). As all sample sites are located at latitudes below 50°, a mixture of C_3 and C_4 vegetation can be expected to have grown in the study area, with C_3 plants being the most common. In general, C_4 plants favour saline environments and are therefore associated with the arid environments of the North Pontic and southern Russian steppes. Shishlina and colleagues (2012, 183) propose that C_4 plants only started growing in some parts of the steppe during the 3rd millennium period of increasing aridity and were subsequently incorporated into sheep fodder. According to Iacumin and colleagues (2004b, 39), C_4 plants represent 20 to 30 % of the steppe grasses in modern Russia and similar proportions can be extrapolated for the steppe vegetation in the Eneolithic and Bronze Age due to the fact that the vegetation zonation in the west Eurasian steppe belt has not significantly changed since around 4000 BC. The typical steppe was restricted to the southern margin of the Pontic lowland, which means that Vinogradnoe is the only study site that is in the zone of *Graminae* steppe on chernozem soils and broad-leaved forests with hornbeam on grey-podzolic soils. All other North Pontic sites investigated here are in the zone of forbs steppe on chernozem soil and oak-hornbeam forests on dark grey soils (Pashkevich/Gerasimenko, 2009, 47, fig. 2).

Movements between vegetation with varying proportions of C_3 and C_4 plants, e.g. in the foreland of the Caucausus Mountains on a seasonal basis between mountain summer pasture (C_3 plants) and steppe winter pasture (C_3 and C_4 plants), would be indicated by scattered $\delta^{13}C$ values in faunal individuals and mixed values in human individuals (Iacumin et al., 2004b, 44–46). Variations should also occur between pastures at significantly different latitudes, but these variations are less marked. In this study, the negligible number of animal bones and the very small number of human bones per chronological period at each site make the investigation of these variables rather complicated. The limited intra-site $\delta^{13}C$ variation does not suggest regular movements between C_3 and C_4 based pastures. Only Vinogradnoe (0.53 ‰) and Benkovski (0.76 ‰) show slightly higher variations. It should be noted, however, that these individuals belong to different time periods and that the intra-site $\delta^{13}C$ variations might have other explanations.

Freshwater and marine fish consumption is indicated by elevated $\delta^{15}N$ values compared with the $\delta^{15}N$ of terrestrial herbivores. While the isotopic values for a consumer of a 100 % marine fish diet would be expected to yield average $\delta^{13}C$ values of –13 ‰ and $\delta^{15}N$ values of up to 18 ‰ (van der Plicht et al., 2006, table 1; in contrast $\delta^{13}C$ –19 to –9 ‰ and $\delta^{15}N$ 8 to 15 ‰ in Schoeninger/DeNiro, 1984; O'Connell

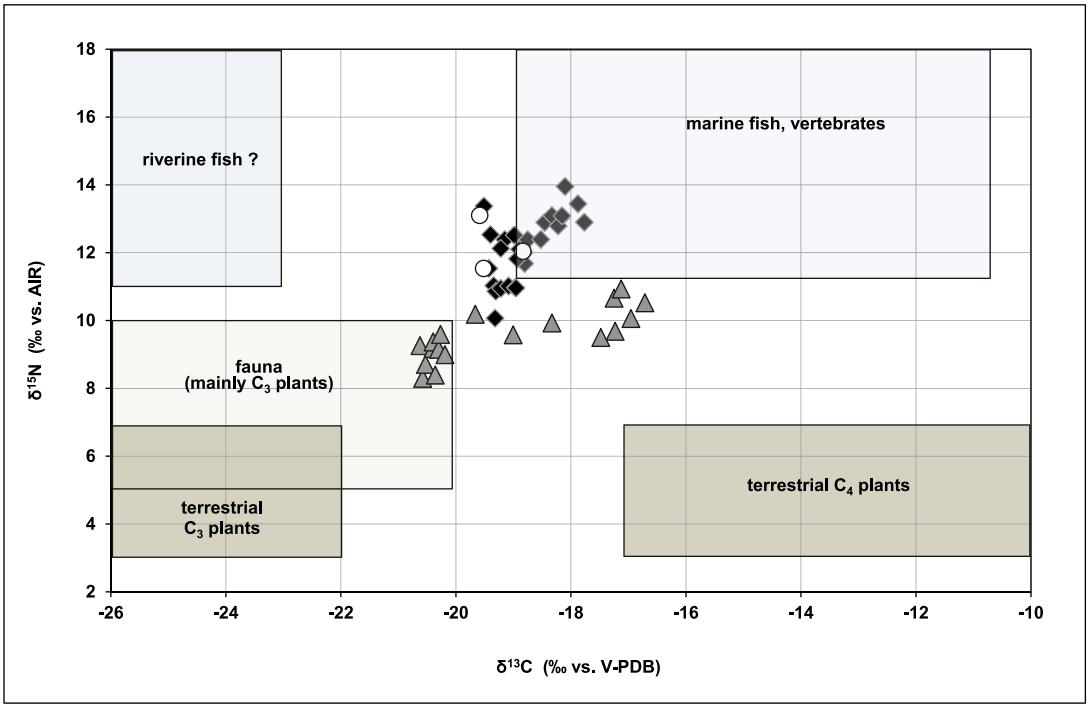


Fig. 6.16 | $\delta^{13}C$ and $\delta^{15}N$ data for the sites in the North Pontic (black diamonds), the Kuban region (white circles) and the West Pontic (grey triangles) plotted against expected stable isotope values for terrestrial and aquatic dietary components (values as given in Privat, 2004, fig. 3.16, table A 1.9; Schäuble, 2005, table 4, fig. 89).

et al., 2003, 258), freshwater fish consumption is difficult to prove using stable isotopes, due to the potentially wide-ranging and overlapping values expected for foods deriving from freshwater sources. Mainly, however, freshwater fish consumption is characterised by depleted $\delta^{13}C$ and enriched $\delta^{15}N$ values. A number of isotopic studies, however, imply that fish was a major source of dietary protein for the prehistoric inhabitants of the steppes (O'Connell et al., 2003; Privat, 2004; van der Plicht et al., 2006; Shishlina et al., 2007; 2009; 2012; Hollund et al., 2010).

Figure 6.16 shows the data of the present study alongside potential dietary components. The results from the North Pontic sites can be interpreted as reflecting a major input from terrestrial meat or other animal products. A trophic level enrichment of $\delta^{15}N$ 3 to 5 ‰ upon typical herbivore isotope ratios, which from this chronological and geographical location would be expected to yield values of approximately 5.8 ‰, would result in nitrogen isotope ratios of approximately 9 to 11 ‰ in their consumers. It can thus be argued that another $\delta^{15}N$ enriched dietary component is of importance since cultivated and gathered plants with low $\delta^{15}N$ values almost certainly also contributed to the overall $\delta^{15}N$ signature. Such a scenario is likely to be the case at least for the humans with higher $\delta^{15}N$ values. A pattern of lower nitrogen isotope ratios in Kirovograd and higher values in Vinogradnoe, however, hint to an additional climatic influence associated with the geographical position. This is supported by the slight correlation in the North Pontic between $\delta^{13}C$ values from the northernmost site Kirovograd, and increasingly enriched $\delta^{13}C$ values from the sites of Peshtchanka and Shakhta Stepnaya, which lie at more southerly latitudes, culminating in the most enriched values deriving from the southernmost site of Vinogradnoe. C_3 plants seem to be the predominant component of the diet. Since the proportion of C_4 plants declines with increasing latitude, a correlation between geographical position, climatic conditions and $\delta^{13}C$ ratios

can be expected. In addition, $\delta^{13}C$ values vary with temperature and density of forests or grasslands, which leads to the same result. This is underpinned by the correlation between high $\delta^{13}C$ values at the driest and warmest site and lower $\delta^{13}C$ ratios at the most humid site. Climatic variations between the North Pontic sample sites are small, which is reflected by small $\delta^{13}C$ differences. In the North Pontic and south Russian steppes, a significant impact from freshwater products on the protein dietary components, leading to increased $\delta^{15}N$ values of consumers has been observed in various studies (Lillie/Richards, 2000; O'Connell et al., 2003; Privat, 2004; Shishlina et al., 2007; 2009; 2012; Lillie et al., 2009; 2011; Hollund et al., 2010). High $\delta^{15}N$ values for most individuals in the North Pontic and the Kuban region also infer the influence of freshwater components, since the nitrogen isotope ratios are more enriched than would be expected for pure C_3 terrestrial herbivore eaters. All sites are located in the vicinity of a river, which suggests some impact of freshwater fish consumption, although there is no compelling coherence between littoral settlements and the consumption of aquatic resources (Hedges/Reynard, 2007, 1244). An influence from marine fish can probably be excluded for all the study sites due to their inland location, except Vinogradnoe and Olennii, from where the sea coast might have been visited as part of a seasonal movement pattern. The more $\delta^{13}C$ enriched values for Vinogradnoe indeed may suggest a marginal impact of C_4 plants or of marine resources. This is not true for Olennii, located in the piedmont of the north Caucasus where a mixed signal of C_3 and C_4 vegetation would be expected (Hollund et al., 2010, 2975) but is not evident in the stable isotope data, which in fact implies a C_3 terrestrial plant based diet.

Humans sampled from Benkovski and Boyanovo in the West Pontic have $\delta^{15}N$ values around 10 ‰. Only humans from Smyadovo yielded values below that, indicating a major contribution of terrestrial C_3 plant derived foods and probably only a minor impact from animal meat and other products. According to the mean $\delta^{15}N$ values derived from different reference studies from Bulgaria, C_3 terrestrial herbivores average around 5.6 ‰ and their consumers are therefore expected to lie between $\delta^{13}C$ –19.5 to –18 ‰ and $\delta^{15}N$ 8 to 11 ‰. The stable isotope results from Smyadovo indicate an almost purely terrestrial C_3 diet, including plants and herbivores. The diets of the humans from Benkovski and Boyanovo led to bone collagen isotope signatures that are slightly enriched in $\delta^{15}N$, but still typical for terrestrial C_3 herbivore consumers, and enriched in $\delta^{13}C$, which indicates some impact of C_4 plants. Hoekman-Sites and Giblin (2012, 521 fig. 5, 6) investigated palaeodietary patterns in the Hungarian Plain and compared their data set of 83 samples from the Late Neolithic and Copper Age with a data set (n= 14) from the Early and Middle Neolithic, obtained from Whittle et al. (2002) and Reynard and Hedges (2008). A shift in the nitrogen isotope ratios from lower values in the Early and Middle Neolithic to higher ones in the Late Neolithic and the Copper Age was interpreted as an increasing use of secondary products like meat, dairy and manure (Hoekman-Sites/Giblin, 2012, 520). A chronologically related shift in $\delta^{15}N$ is also present in the data from Bulgarian sites in this study, which might be interpreted as indicating a greater use of secondary products in the Early Bronze Age. Increased dairy and meat consumption might be related to an intensification of husbandry activities, but as Bogaard and colleagues (2007) were able to show, manuring also leads to enrichment in $\delta^{15}N$ and this is passed on to animals or people eating the resultant crops.

A major impact from marine or freshwater resources can probably be ruled out. The enrichment in $\delta^{13}C$ due to the consumption of marine resources is rather unlikely because of the geographical position of the sites. Major consumption of freshwater resources was attested in the West Pontic for the Mesolithic and Neolithic humans in the Iron Gate region, where $\delta^{15}N$ values of $\geq$ 14 ‰ in association with $\delta^{13}C$ values significantly lower than –20 ‰ were seen as being characteristic for a mainly aquatic diet

(Bonsall et al., 1997; 2000; Cook et al., 2001; Nehlich et al., 2010). The stable isotope ratios in the present study, however, do not indicate this kind of freshwater fish impact.

Consequently, it can be stated that terrestrial C_3 fauna and faunal products formed the basis of the diets of people buried at Benkovski and Boyanovo. According to climate simulations, there was no major change in humidity between the Eneolithic and the Early Bronze Age (Körper et al., in prep., fig. 3, 4) that would explain the intra-regional variations in the stable isotope values; therefore the data might point to an intensified use of secondary products at that time.

The enrichment in $\delta^{15}N$ in the samples from the North Pontic and Kuban region compared to the West Pontic region can most plausibly be explained by the addition of foods from freshwater sources, to more arid climatic conditions or to a combination of both factors. Enriched $\delta^{15}N$ values can be related to higher trophic levels, but can also reflect more arid areas or time periods, since animals in areas with less rainfall are exposed to water stress and elevated $\delta^{15}N$ in plants results from aridity and high salinity (Hollund et al., 2010, 2982; Lee-Thorp et al., 1993, 102–103). In this study, different levels of aridity, as well as the period of increasing aridity from the first half of the 3rd millennium BC onwards, could be the main causes for varying $\delta^{15}N$ values. Astonishingly, this $\delta^{15}N$ enrichment is only evidenced in the faunal material from south Russia but not in the animals from the North Pontic. This might be a reason to favour a freshwater fish explanation for the North Pontic region, in combination with climatic reasons to a more minor degree for the regional variation in nitrogen isotope ratios.

6.6.5 Comparison of the results for human bone to analogous studies

6.6.5.1 North Pontic region

The human bones from the four sites in the North Pontic region yielded values from $\delta^{13}C$ –19.51 to –17.77 ‰ and $\delta^{15}N$ 10.07 to 13.95 ‰. The closest regional references for comparison are the studies in the Dnieper Rapids region by M. Lillie and colleagues (Lillie et al., 2012 with older literature) and the study in central and eastern Ukraine by K. Privat (Privat, 2004, see also O'Connell et al., 2003) (Fig. 6.17, Table 6.3).

In multiple studies by Lillie and colleagues, a series of 113 samples of humans, herbivores and riverine fish dating to time periods between the Epipalaeolithic and the Eneolithic were selected for stable carbon and nitrogen isotope analysis, mainly to investigate dietary changes at the transition from the Mesolithic to the Neolithic (cf. Lillie et al., 2011; 2012). The results did not suggest significant differences in the consumption of terrestrial plant food and only minor changes in the consumption of freshwater resources (Lillie et al., 2011 incl. older lit.). The human bones that dated to the Neolithic and Eneolithic from a range of sites in the Dnieper Rapids region yielded values between $\delta^{13}C$ ca. –24 and –19 ‰ and $\delta^{15}N$ ca. 10 to 15.5 ‰ with values mainly between $\delta^{13}C$ –23 and –21 ‰ and $\delta^{15}N$ 10 to 13 ‰ (Lillie/Richards, 2000, 966 table 1; Lillie et al., 2009, 260 table 3). Enriched nitrogen isotope ratios in association with depleted carbon isotope ratios were interpreted by the authors as reflecting a diet in which freshwater products played an important role. It is remarkable that the Eneolithic and Bronze Age samples in the present study revealed similar $\delta^{15}N$ but less depleted $\delta^{13}C$ values compared to the chronologically earlier samples from the Dnieper Rapids region. This might be explained by climatic factors like increased aridity or by economic differences.

The results for human bones dating to the Bronze Age Yamnaya and KMK (multiroller) cultures that derived from a forest-steppe/steppe site in central Ukraine and several sites in eastern Ukraine are less depleted in $\delta^{13}C$, but similar in $\delta^{15}N$ (Privat, 2004). The results of the present study are comparable to the eleven samples from eight sites, averaging at –19.07 ± 0.41 ‰ and 12.23 ‰ ± 0.91 ‰ for $\delta^{13}C$ and $\delta^{15}N$ respectively, with ranges between –19.5 to –18.6 ‰ and 10.8 to 13.7 ‰ respectively (Privat, 2004, table A1.8). In that study, eight human bones from two steppe sites dating to the Scythian period were also analysed, which yielded $\delta^{13}C$ values of –17.4 to –14.1 ‰ and $\delta^{15}N$ values of 10.5 to 12.1 ‰, with average means of –16.04 ± 1.3 ‰ and 11.28 ± 0.53 ‰ respectively (Privat, 2004, table A1.11). Compared to the Bronze Age humans, the Scythian individuals are less depleted in $\delta^{13}C$ and slightly less enriched in $\delta^{15}N$. Privat interprets the data as reflecting subsistence, in which terrestrial herbivores and domesticate products provided the basis of the diet, but the importance of freshwater fauna such as fish and agricultural products needs to be stressed. Notably the C_4 plant millet became increasingly important in the Iron Age (Privat, 2004, 82). The impact of C_4 plants upon an otherwise C_3 based diet was also evidenced in three Scythian samples from Alexandropol' in central Ukraine, where $\delta^{13}C$ in apatite ranged between –12.2 and –10.4 ‰ (Wentz/de Grummond, 2009, 113–114).

26 human bone samples from three sites in south Russia and the northeast Black Sea coast deriving from different prehistoric chronological periods were collected by Iacumin et al. (2004b, 42–43 table 2). The highly varying $\delta^{13}C$ (–19.5 to –12.1 ‰) and $\delta^{15}N$ values (9.2 to 18.1 ‰) can partly be explained by different geographic site locations but also by the differences in the herbivorous stable isotopic values and varying diets. The results do not only indicate a terrestrial food based diet with different gradients of C_4 plant impact but also of aquatic resources (Iacumin et al., 2004b, 43–46). Shishlina and colleagues investigated the diet of the Eneolithic and Bronze Age populations in the northwest Caspian steppe and the North Caucasus piedmont based on an extended data set of approximately 100 skeletons (Shishlina, 2008; Shishlina et al., 2009; 2012; van der Plicht et al., 2006). They found that pastoralism, the assumed economic system of the Early Bronze Age in the Caspian steppe, was confirmed by a general enrichment in nitrogen isotope values arising from the consumption of herbivore meat as well as riverine food (Shishlina et al., 2009, 484). The authors found evidence of a period of increasing aridity between the 5th to the 3rd millennium BC using stable isotope analysis, shown by a general trend of increasing $\delta^{15}N$ values (Shishlina et al., 2012). In addition, and reflected by the $\delta^{13}C$ values, the presence of C_4 plants in the steppes increased due to the progressively more arid climate after the middle of the 3rd millennium BC. While the Eneolithic humans dating between 4300 and 3800 cal BC had values between $\delta^{13}C$ –22 and –20 ‰ and $\delta^{15}N$ 9 to 14 ‰, the individuals from the Yamnaya period had less depleted $\delta^{13}C$ (ca. –19 to –15.4 ‰) and enriched $\delta^{15}N$ (ca. 10.5 to 18 ‰) values. These differences were explained by access to a wider range of food resources over time associated with the expansion of the steppes (Shishlina et al., 2009, 484–485). According to the authors, the economic background of the Steppe North Caucasus people, dating to 2500–2300 cal BC, was based on agriculture alongside herding and gathering of river products and wild plants (Shishlina et al., 2009, 486–487). The results of the present study are consistent with the stable isotope results of the Yamnaya humans, averaging around –18 ‰ for $\delta^{13}C$ and between ca. 12 and 16 ‰ for $\delta^{15}N$. The wide spread of stable isotope values (ca. –18 to –15.4 ‰ for $\delta^{13}C$, ca. 9.5 to 18.6 ‰ for $\delta^{15}N$) for the subsequent East Manych Catacomb culture human individuals (2500–2000 cal BC) is explained by the authors as coming from highly variable and often elevated isotope values in the herbivores due to the assumed climatic drying process during this period (Shishlina et al., 2009, 497). Shishlina and colleagues find it difficult to confirm changing subsistence patterns during the Eneolithic, the Early and the Middle Bronze Age using stable isotopes, due to non-

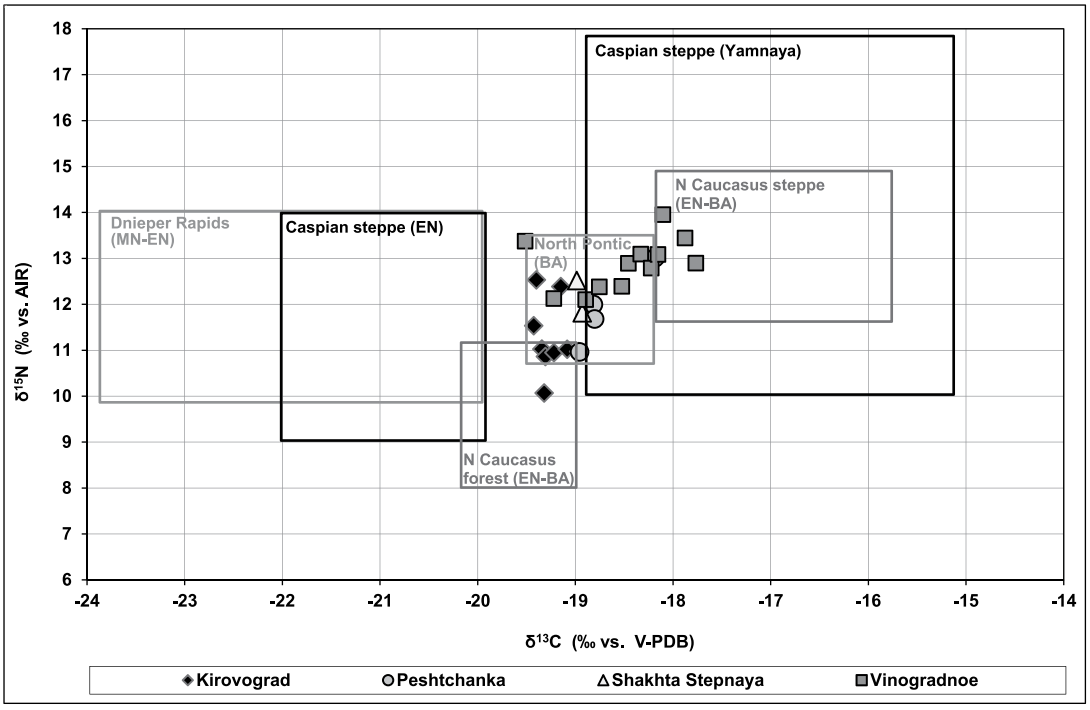


Fig. 6.17 | $\delta^{13}C$ and $\delta^{15}N$ data for the North Pontic plotted against isotopic results from comparable studies.

changing dietary components but they emphasize the importance of river and lake food besides herbivore products and plant gathering (van der Plicht, 2006, 122; Shishlina et al., 2009, 488–490).

The sites in the North Pontic investigated here yielded $\delta^{13}C$ and $\delta^{15}N$ values that are at the lower end of the ranges given by Shishlina, which may indicate a minor aquatic component, a predominant role of C_3 plants (gathering or farming) and animals feeding on them (animal husbandry), a minor importance of C_4 plants due to less arid and saline environmental conditions or simply climatic differences. In general, the results of the present study find their best match in the stable isotope ratios of the North Pontic sites investigated by Privat (2004), which are also closely comparable in time and space. Another match for the values from Kirovograd are the results from the North Caucasus forest zone. The similarity might be caused by ecological and/or climatic parallels, despite the significant distance between the two sites. The other sites sampled find their best matches in the results for the Yamnaya and other prehistoric individuals from the Caspian steppe. The samples from the present study yielding most enriched stable carbon isotopes compare well with the North Caucasus steppe individuals. Stable isotope results from Eneolithic individuals from the Caspian steppe and Mesolithic to Eneolithic individuals from the Dnieper Rapids region, on the other hand, differ due to more depleted stable carbon isotope values in these studies.

6.6.5.2 Kuban region

The mean $\delta^{13}C$ and $\delta^{15}N$ values for the three individuals from Olennii are not very consistent and compare most closely with the North Pontic results of Privat (2004). Another reference for comparison is provided in the study of Hollund et al. (2010), who investigated 17 sites in the North Caucasus ranging

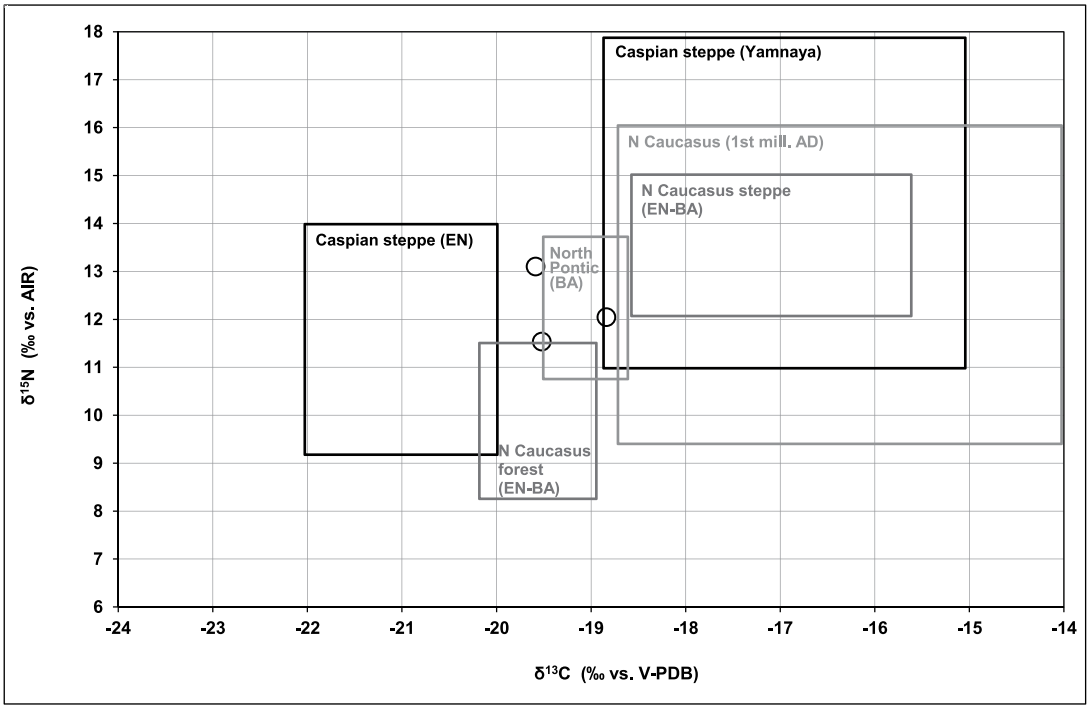


Fig. 6.18 | $\delta^{13}C$ and $\delta^{15}N$ data for Olennii plotted against isotopic results from comparable studies.

in time from the Eneolithic to the Middle Bronze Age (Fig. 6.18, Table 6.3). As well as 60 human bones that were analysed for $\delta^{13}C$ and $\delta^{15}N$ ratios, 48 faunal skeletal remains were also measured to provide a solid base of possible protein sources (Hollund et al., 2010, tables 1, 2). They found that stable isotope ratios mainly depended on ecological and climatic factors, with $\delta^{15}N$ increasing with aridity and $\delta^{13}C$ values decreasing with precipitation (Hollund et al., 2010, 2979–2982). The human values of the study sites closest to Olennii that are situated in the humid, middle and dry steppe are $\delta^{13}C$ –18.4 to –16.1 ‰ and $\delta^{15}N$ 12.1 to 15.2 ‰, while the isotopic values of the sites closest to Olennii located in the forest zone of the North Caucasus are $\delta^{13}C$ –20.2 to –19 ‰ and $\delta^{15}N$ 8.3 to 11.5 ‰ (Hollund et al., 2010, table 2). The $\delta^{13}C$ and $\delta^{15}N$ values from Olennii are comparable, lying approximately in between the results for the steppe and forests. This could indicate a subsistence that is based on different ecological niches. Even some kind of pastoralism with different summer and winter pastures is imaginable but, due to the small sample size, interpretation of the data remains speculative. The isotopic data of Higham et al. (2010) from human remains from a 1st millennium AD site in the North Caucasus are less depleted in $\delta^{13}C$, which might indicate a major influence of C_4 plants in the diet.

6.6.5.3 West Pontic region

The human bones from the Bulgarian study sites yielded values from $\delta^{13}C$ –20.62 to –16.71 ‰ and $\delta^{15}N$ 8.29 to 10.93 ‰. Reference material for comparison comes from the study of Honch et al. (2006), in which two sites, the cemeteries Varna I and Durankulak, both situated near the Black Sea coast, were examined using a stable isotope-based approach (Fig. 6.19, Table 6.3). Durankulak dates to the 1st half

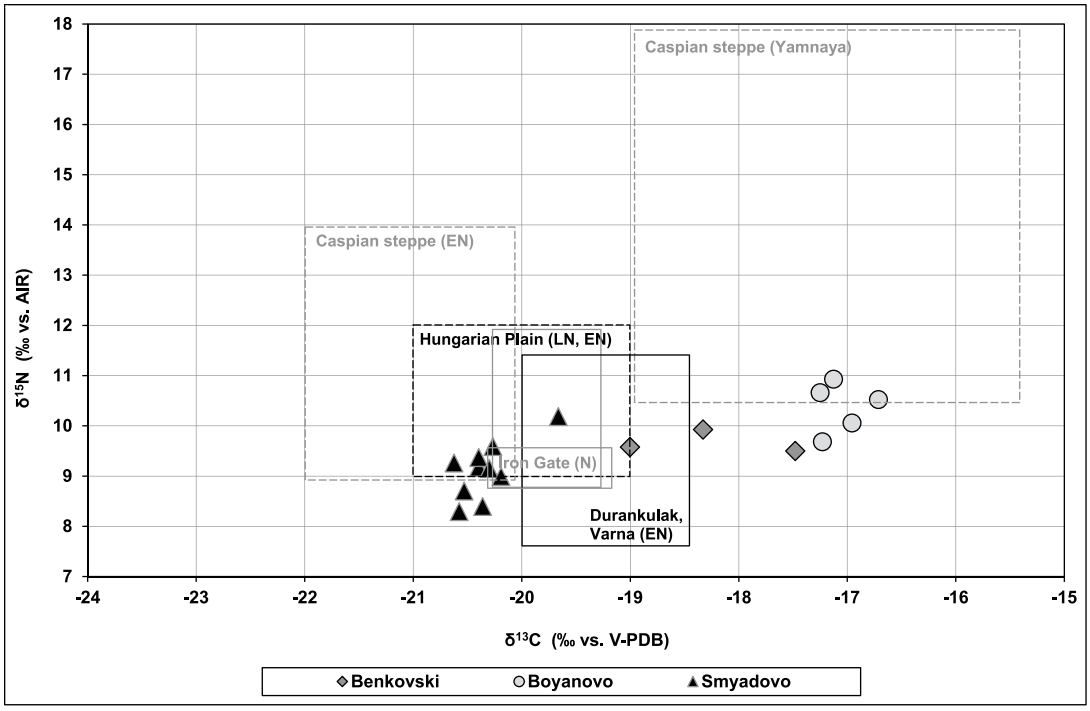


Fig. 6.19 | $\delta^{13}C$ and $\delta^{15}N$ data for the West Pontic sites plotted against isotopic results from comparable studies.

and Varna I to the middle of the 5th millennium BC. In terms of chronology and geographical location, the results of Honch's study are most comparable to Smyadovo in the present study, because Ovchartsi and Boyanovo are of younger date and further away. The 55 samples from Varna I average at –19.3 ± 0.3 ‰ $\delta^{13}C$ and 10.0 ± 0.6 ‰ $\delta^{15}N$. The stable isotope measurements from 78 samples from Durankulak give means of –19.1 ± 0.3 ‰ $\delta^{13}C$ and 9.3 ± 0.8 ‰ $\delta^{15}N$ (Honch et al., 2006, 1497). The data was interpreted by the authors as reflecting a diet based on C_3 plants with an important impact of terrestrial meat sources. The slightly enriched $\delta^{13}C$ and $\delta^{15}N$ values, compared to inland continental European sites with a mean of around –21 to –20 ‰, are interpreted as being caused by the increase of temperature and aridity (Honch et al., 2006, 1497). While the mean values for the individuals from Boyanovo and Benkovski are > 2 ‰ enriched than the values of Honch and colleagues, the individuals from Smyadovo yielded $\delta^{13}C$ values that are around 1 ‰ more depleted. Considering that the $\delta^{15}N$ values of 9.11 ± 0.56 ‰ (Smyadovo), 9.67 ± 0.23 ‰ (Benkovski) and 10.37 ± 0.54 ‰ (Boyanovo) are comparable to Varna I and Durankulak, the results suggest that the diets at these sites derive from approximately the same trophic level.

The dietary changes of the Mesolithic-Neolithic transition at the Danube Gorges were investigated by multiple studies and produced large data sets of stable isotope results for both human skeletons and fauna (e.g. in Borić et al., 2004: 97 humans from Vlasac and Lepenski Vir and 43 animals from Vlasac). While Bonsall et al. (2000) suggested a dietary shift from one based on aquatic food resources in the Mesolithic to diets primarily based on terrestrial food in the Neolithic, Borić and colleagues (2004) rejected these conclusions as 'overly simplistic and not supported by the existing evidence' on their extended isotopic study at the same sites (Borić et al., 2004, 241). The results from stable isotope analy-

Table 6.3 | $\delta^{13}C$ and $\delta^{15}N$ data ranges for comparable studies in the same study area.

region	age	$\delta^{13}C$ (‰) (vs. V-PDB)	$\delta^{15}N$ (‰) (vs. AIR)	author
West Pontic Black Sea coast	Neolithic, Copper Age	~ –20 to –18.5	~ 8 to 11.5	Honch et al., 2006
Iron Gate	Mesolithic, Neolithic	~ –22 to –18	~ 9 to 18	Bonsall et al., 2000; Borić et al., 2004; Nehlich et al., 2010
Iron Gate	Late Mesolithic	–19.5 to –18.2	13.2 to 15.8	Bonsall et al., 2004
Iron Gate	Early Neolithic	–20.2 to –19.4	9.8 to 11.9	Bonsall et al., 2004
Hungarian Plain	Late Neolithic, Copper Age	~ –21 to –19	~ 9 to 12	Hoekman-Sites/ Giblin, 2012
Dnieper Rapids region	Late Mesolithic	–20.9 ± 0.8	13.4 ± 1.2	Lillie/Richards, 2000; Lillie/Jacobs, 2006
Dnieper Rapids region	Early Neolithic	–22.5 ± 1.0	10.9 ± 1.7	Lillie/Richards, 2000; Lillie/Jacobs, 2006
Dnieper Rapids region	Neolithic, Eneolithic	~ –24 to –20	~ 10 to 14	Lillie et al., 2012
Ukraine	Bronze Age	–19.07 ± 0.41	12.23 ± 0.91	Privat, 2004
Ukraine	Iron Age	–16.04 ± 1.3	11.28 ± 0.53	Privat, 2004
Northeastern Black Sea coast	prehistoric	–15.9 to –15.8	~ 12 to 14	Iacumin et al., 2004
Caspian steppes	Eneolithic	~ –22 to –20	~ 9 to 14	Shishlina et al., 2009
Caspian steppes	Yamnaya	~ –19 to –15.5	~ 10.5 to 18	Shishlina et al., 2009
Steppe North Caucasus	Early Bronze Age	~ –18	~ 12 to 16	Shishlina et al., 2009
Caspian steppes	Bronze Age	–21.54 to –15.29	12.42 to 18.13	van der Plicht et al., 2006
North Caucasus forest zone	Early Bronze Age	~ –20 to –19	~ 8 to 11.5	Hollund et al., 2010
North Caucasus humid to dry steppe	Early Bronze Age	~ –18.5 to –16	~ 12 to 15	Hollund et al., 2010
North Caucasus	1st millennium AD	~ –19 to –14	~ 9 to 16	Higham et al., 2010
Don/Volga region	prehistoric	~ –19.5 to –12	~ 12 to 18	Iacumin et al., 2004

sis in the Danube Gorges region are similar to the $\delta^{13}C$ values from Smyadovo and Benkovski, yet exhibit differences in $\delta^{15}N$ (Bonsall et al., 2003, 124, see table 3), probably due to a major impact of aquatic food resources in the diet of the Danube Gorge humans.

The best match for the Smyadovo individuals is provided by the Neolithic and Copper Age individuals investigated from sites on the Hungarian Plain (Whittle et al., 2002; Reynard/Hedges, 2008; Hoekman-Sites/Giblin, 2012), which are comparable in respect of chronology and environmental conditions. The Hungarian data sets were interpreted as primarily relying on terrestrial C_3 plant and animal food, while any major impact from fish or dairy products is not evident (Hoekman-Sites/Giblin, 2012, 520). Remarkably, the best match for the Boyanovo humans is given by the Yamnaya individuals in the Caspian steppe (cf. Shishlina et al., 2012 incl. older lit.).

6.7 Conclusions Chapter 6

This chapter was dedicated to the reconstruction of the diet in the North Pontic region and adjacent areas during the Eneolithic, the Early and the Middle Bronze Age, by the application of light stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$) to skeletal material (53 human bones and eight teeth) from three sites in Bulgaria, four sites in Ukraine and one site in south Russia. Despite the availability of just six faunal bones, several spatial-temporally similar studies enabled statements to be put forward regarding possible subsistence economies and dietary patterns.

It was found that distinct isotopic groupings correlate with geographical regions. A positive correlation between $\delta^{13}C$ and $\delta^{15}N$ values and latitude was observed at the sites of Smyadovo, Kirovograd, Peshtchanka and Vinogradnoe, which is likely related to their geographical position and climatic conditions. Despite C_3 terrestrial herbivores and plants likely providing the dietary basis of all sampled humans, the West Pontic samples were decisively different to the samples from the North Pontic and Kuban region. Climatic effects can be seen to result in localised differences in $\delta^{15}N$ values, as identified from analyses of herbivore bones from the Bulgarian and Ukrainian sites compared with those from south Russia. However, the degree of elevation of $\delta^{15}N$ values that are exhibited by a significant number of individuals from the North Pontic compared with Bulgaria cannot solely be explained on this basis. Thus it is necessary to suggest a contribution of freshwater fauna, e.g. fish, as a major staple in the diet of the North Pontic steppe people during the Eneolithic and Bronze Age in order to explain these elevated values. In accord with earlier light stable isotope studies in the Ukrainian and south Russian steppes, fishing is suggested to be a major subsistence activity during these periods. In contrast, fishing activities are shown to have had little or no role in the subsistence strategies of the Bulgarian humans, as evidenced in the light stable isotope results. The predominant food sources are plants of C_3 type and animals feeding on them, while C_4 plants seem to be of minor importance except in the Early Bronze Age in Bulgaria, where enrichment in $\delta^{13}C$ hints to an increasing importance of C_4 plants. This is probably due to changes in agricultural activities, such as the cultivation of C_4 plants, e.g. millet. Changing pasture management from more densely to less forested pasture areas can provide another explanation. In the North Pontic region, millet starts to play an important role only in the later Bronze Age and subsequent Iron Age (Privat, 2004, 82; according to Bunyatyan, 2003, 274 millet was cultivated as early as in the Yamnaya period).

Statistical tests were somewhat limited since group sample sizes were mostly too small. Chronological differences are statistically proven between the Yamnaya and Early Catacomb culture and between Early and Developed Catacomb culture at Vinogradnoe. There is, however, no decisive chronological trend. Furthermore, no variations associated with differences in sex could be detected. Minor variations, though statistically not significant, existed between children and adults (in Kirovograd, Peshtchanka and Vinogradnoe), which might be indicators for a meat or fish enriched diet in adulthood, but differences are too minor to interpret this with certainty.

Few decisive statements can be made, which is mainly due to small sample sizes at each site. To get an insight into the diet of the Eneolithic, the Early and the Middle Bronze Age in the North Pontic and West Pontic, the numbers of humans sampled need to be increased. A moderate data set of faunal remains could provide the basis for a reconstruction of a food web and subsequently the basis for the development of mixing models.

In summary, the investigation into palaeodiet on a large scale, and the comparison between different regions, i.e. the North Pontic, the West Pontic and the Kuban region, has enabled not only the detection of dietary changes but also differences due to geographical locations and climatic variations. Based

on her results of stable carbon and nitrogen isotope analysis, Privat stated that the 'currently accepted description of prehistoric Eurasian pastoralist economies needs to be revised' (Privat, 2004, 83). It is certainly true that the diet of the Eneolithic and Early Bronze Age inhabitants is not as simple as assumed for prehistoric herders but very complex. The consumption of C_3 terrestrial herbivores and domesticate products provided the most important dietary component in the North Pontic and the Kuban region, but the diet of the steppe communities during the Eneolithic and Early Bronze Age had more facets than purely herbivore meat, i.e. gathered plants and maybe a limited amount of agricultural products as well as freshwater products. The shift between the West and North Pontic results can most probably explained by climate differences, since both humans and herbivores show a shift in their isotope values. In addition, it is probable that aquatic resources played a minor role in the West Pontic region.

7 Summaries in English, German and Russian

This scientific-archaeological study focused on the reconstruction of mobility and diet in the West Eurasian steppes in the period between 3500 and 300 BC using $^{87}Sr/^{86}Sr$, $\delta^{18}O$, $\delta^{15}N$ and $\delta^{13}C$ analyses. It was a subproject of research group A II *Spatial effects of technological innovations and changing ways of life* within the framework of the Excellence Cluster *Topoi*. The study covered a vast area that has been subdivided into representative micro-regions or single sites, namely Bulgaria and Hungary in the Carpathian-Balkan region, central and eastern Ukraine in the North Pontic region, the sites in the Kuban region, the northwest Caspian steppe and in the Middle Volga region in Russia and one site in Kazakhstan, in Central Asia. Samples were selected from sites dating to the Eneolithic, the Early and Middle Bronze Age and the Iron Age and can be associated with four time periods; the late Eneolithic in the second half of the 4th millennium BC, the Early Bronze Age Yamnaya culture that dominates the first half of the 3rd millennium BC and the subsequent Catacomb culture, which can be dated to the second half of the 3rd millennium BC as well as cultural groups of the Scythian period in the 1st millennium BC. Tooth and bone samples were selected for multi-isotope analysis, i.e. $^{87}Sr/^{86}Sr$, $\delta^{18}O$, $\delta^{15}N$ and $\delta^{13}C$ analyses. The basic questions concerned the mobility and dietary patterns of these cultural groups. It was also interesting to see whether differences in stable isotope ratios could be identified in the periods immediately before and after 3000 BC, which is when specialised cattle husbandry emerged and means of transport like wagons or wagon parts appeared as grave furniture. Furthermore, the widespread and highly consistent burial traditions in the North Pontic and adjacent regions imply wide-ranging cultural contacts. Changes in climate are thought to have occurred at this time, with palaeoclimatic studies suggesting that a period of increasing aridity started around the late 4th millennium and is evident throughout the whole 3rd millennium BC. All this might have led to shifts in lifestyle with an increased degree of mobility. As a basis for comparison, samples were taken dating to the Scythian period in the 1st millennium BC, a time associated with the emergence of fully-fledged nomadism and mounted warfare and therefore implying highly developed mobility.

The introduction of the study aims as well as the geographical and chronological attribution of the study sites in chapter 1 are followed by the description of the archaeological cultures related to the sampled human individuals, an overview of the applied methods and an introduction to the choice of sampling material in chapter 2. In chapter 3, the sample sites are briefly described. The selection of sites, in which the author was not involved, followed the principle of gaining a representative cross-section of the study region. It was unfortunately not taken into consideration that sample sizes per site and micro-region should be statistically relevant and a numerical consistency of sex and age and chronological groups was not attempted. These factors complicated the evaluation of the data significantly.

The study was separated into two main sections; the first focused on mobility and migration of the steppe people in the periods mentioned above, while the second dealt with their dietary behaviour. The mobility and migration study included the analysis of $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ in tooth enamel samples from 142 human individuals. The use of $\delta^{15}N$ and $\delta^{13}C$ analysis on the bone of 54 human individuals from selected sites in the West Pontic, the North Pontic and the Kuban region provided the basis of the palaeodietary study. These two studies are regarded as separate investigations due to varying sample bases.

Mobility theories are frequently mentioned but not often included in archaeological research. In this study common theories of mobility and migration were introduced and discussed at the beginning

of chapter 4. Their application to the study region was relatively complicated, since the cultures being examined here are associated with a number of elements of uncertainty. The definition of the boundaries between the Eneolithic steppe cultures and the regional variants of the Early Bronze Age is rather vague and disputed in archaeological research. Their economies are heavily disputed and can only be regarded as being primarily based on specialised cattle husbandry that implied some kind of increased mobility. The mobility ranges and their directions, however, remain highly speculative. Settlement sites are rare and even less frequently archaeologically investigated. Temporary, probably seasonal, camps are sometimes indicated, for example in the northwest Caspian region, but there is also evidence of settlements that were permanent or at least occupied for long periods, for example along the lower Dnieper. References for possible migration cycles, for example circular or resource-related ones, do not exist. Furthermore, the last places of residence of supposedly mobile communities do not necessarily equate to the burial places. This issue questions the value of collecting reference samples to establish the 'local' isotopic signatures in the burial mound environment.

Both $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses depend on varying factors; this is basically geology for $^{87}Sr/^{86}Sr$ and multiple factors like amount of precipitation, temperature, distance from the ocean, altitude and latitude for $\delta^{18}O$. The combination of $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses led to high-quality results, which enabled the identification of micro-regions, including some overlaps, and simplified the identification of outlier values. The results of the strontium isotope analysis varied; Consistent $^{87}Sr/^{86}Sr$ values were achieved for sites like Benkovski (Bulgaria), Nevskoe (Ukraine) and Olennii (Russia), whereas other sites such as Ovchartsi (Bulgaria), Kirovograd (Ukraine) and the sites in the Middle Volga region (Russia) showed much more variability in the $^{87}Sr/^{86}Sr$ values. These patterns were not reflected in the $\delta^{18}O$ values, however. Sites featuring homogeneous $^{87}Sr/^{86}Sr$ values showed more variable $\delta^{18}O$ values, for example Vinogradnoe and Nevskoe (both Ukraine), while sites with divergent $^{87}Sr/^{86}Sr$ values had less varied $\delta^{18}O$ values, e.g. Kirovograd (Ukraine). The combination of both isotopic systems made it possible to distinguish between different mobility patterns. Nevertheless, the question of whether these differences are related to larger mobility ranges, to different social organisation or to varying data sets remains unexplained. Similar isotopic results were repeatedly associated with the use of the kurgans over just one cultural period, perhaps equivalent to one single community, for example in Nevskoe (Ukraine), Olennii and Sukhaya Termista (Russia), while widely distributed isotopic results often correlated to a diachronic use of the burial mounds, for example in Kirovograd and Peshtchanka (Ukraine). Nevertheless, there were also contradictory examples. Intra- and interregional comparisons were complicated by varying strategies in reference sampling. Regardless of the varying levels of reliability of the reference samples, it was suggested that the data for the Eneolithic and the Yamnaya period in the western study areas were more widely dispersed than the isotope values of other regions. Only small ranges were evident for the Early Catacomb culture. Strontium and oxygen isotope patterns seemed to marginally shift over time, which might be associated with the beginning of a period of increasing aridity and/or an economic change and the appearance of partly mobile pastoralism at the end of the 4th millennium BC. No higher degree of mobility could be identified isotopically for unusual graves like wagon burials.

The relatively restricted ranges of isotope values from the Scythian samples from the North Pontic sites can be interpreted as limited or non-detectable mobility. Alternatively, it could be that movement is not visible isotopically because of the homogeneous nature of expected isotope ratios across this wide-ranging region. The different locations of the sites and the isotopic variations seen within some sites argue against interpreting the sampled Scythians of the North Pontic as one residence community. A higher degree of mobility, perhaps suggesting patterns of transhumance, were indicated by larger

$^{87}Sr/^{86}Sr$ and $\delta^{18}O$ ranges and standard deviations in the humans and horses from the Kazakh Altai Mountains, also dating to the Scythian period. A case study on a triple cattle deposition from Zauschwitz (Germany) affiliated to the Globular Amphora culture, which has chronological and economic parallels to the Yamnaya culture, showed differing animal movement patterns, some of which also suggested transhumance. The application of $^{87}Sr/^{86}Sr$ laser ablation in this context gave excellent results and strengthened the interpretation of regular mobility.

The data obtained from $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analyses neither absolutely confirmed nor contradicted possible migrations into the regions west and southwest of the distribution areas of larger groups of the Eneolithic steppe cultures and the Early Bronze Age cultures of the North Pontic region. The $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ results of several individuals from Hungarian burial mounds indicated the presence of migrants, which complied with the archaeology. The dispersed $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values of some individuals from the Bulgarian sites, which would agree with values expected for the North Pontic region, also corresponded with the archaeological evidence and inferred immigration. The data obtained from $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ isotope analyses did not indicate foreign origins for other individuals that are also buried according to North Pontic burial traditions. Due to a relatively small data set and the lack of a good archaeological characterisation of the contemporaneous local burial practices, further analyses are needed to support or discard suggested migrations.

In addition to the investigations into mobility and migration, a palaeodietary study using $\delta^{13}C$ and $\delta^{15}N$ analysis was conducted on human skeletal material that derived from three sites in Bulgaria, four sites in Ukraine and one site in the Kuban region. Statistical tests proved a correlation between $\delta^{13}C$ and $\delta^{15}N$, which coincided with the geographical locations and their climatic conditions. Besides C_3 terrestrial herbivores and plants providing the dietary basis of all sampled human individuals, the West Pontic, i.e. the Bulgarian, samples were distinctly different to the samples deriving from the North Pontic and the Kuban region. A shift of approximately 3 ‰ in $\delta^{15}N$ values between the herbivore bones from the Bulgarian and Ukrainian sites in reference studies and the present study versus the herbivore data from south Russia was observed, which can best be explained by the differing climatic conditions. The prevalence of significantly higher $\delta^{15}N$ values among humans from the North Pontic and the Kuban region compared to Bulgaria might additionally be the result of the dietary addition of freshwater fauna by the North Pontic steppe people during the Eneolithic and Bronze Age. In concurrence with earlier light stable isotope studies in the West Eurasian steppes, it was suggested that fishing and the exploitation of freshwater resources were major subsistence activities during these periods. Evidence of fishing activities for the Bulgarian humans, on the contrary, was slight to non-existent but the isotope signatures of the Early Bronze Age human individuals in this region hinted to an increased impact of C_4 plants. This is potentially due to changes in agricultural activities such as the cultivation of C_4 plants like millet. In the North Pontic region, on the other hand, there is no clear evidence of millet consumption or production in the Early Bronze Age and it only starts to play an important role in the later Bronze Age and subsequent Iron Age. Statistical tests were applied with severe limitations as group sample sizes were mostly too small. Chronological variations were statistically proven between the Yamnaya and the Early Catacomb cultures and between the Early and the Developed Catacomb cultures at Vinogradnoe. There was, however, no decisive chronological trend. Marginal variations existed between children and adults, which might be indicators for a meat- or fish-enriched diet in adulthood, while no variations associated with differences in sex could be detected. In conclusion, the large-scale palaeodietary investigation enabled the detection of dietary changes as well as changes based on climate variations associated with geographical and/or chronological changes between the West Pontic, the North Pontic and the

Kuban region. The consumption of C_3 terrestrial herbivores and domesticate products provided the most important dietary component but the diet of the steppe communities during the Eneolithic, the Early and Middle Bronze Age probably had more facets than only herbivore meat, namely freshwater resources and plants. In addition to a minor impact of fish consumption, the most probable explanation for the differences between the West and the North Pontic data is climatic variations and differences in forest cover. A more profound insight into the diet of the Eneolithic and Bronze Age individuals in the investigated regions would require the extension of the sample sizes of both humans and animals and the establishment of a reconstructed food web, which would further provide the basis for the development of mixing models.

It became apparent that the sampling of such a vast study area is extremely complicated and sampling strategies certainly need to follow the same standards as in the investigation of single sites. Statistically relevant sample sizes of human individuals as well as food and water sources and the isotopic characterisation of the immediate environs are required to enable clear conclusions. Therefore, as a substitute for large-scale random sampling, it is suggested that a few kurgan sites be selected, where diachronic analysis and a profound and systematic characterisation of the environment would be possible. It could be shown that the study area is isotopically distinguishable, however, which would provide a sound base for future studies using stable isotope analysis in the same study area. Although questions about mobility and dietary patterns and migrations of the Eneolithic, Early and Middle Bronze Age and Iron Age individuals in the West Eurasian steppes could only be answered speculatively rather than conclusively, this study nevertheless provides an excellent starting point for further isotope work.

Die vorliegende Studie vereinte Methoden aus der Archäologie und den Naturwissenschaften um das Mobilitäts- und Ernährungsverhalten der Menschen in der Westeurasischen Steppe im Zeitraum zwischen 3500 und 300 v. Chr. zu beleuchten. Es handelte sich dabei um ein Subprojekt der Forschergruppe A II *Spatial effects of technological innovations and changing ways of life* des Exzellenzclusters *Topoi*. Im Rahmen der Studie wurden repräsentative Mikroregionen sowie einzelne Fundorte im Karpaten-Balkan-Raum (in Bulgarien und Ungarn), im Nordpontikum (im südlichen Bereich der zentralen Ukraine und in der Ostukraine), in Russland (im Kuban-, dem nordwestlichen Kaspigebiet und in der Mittleren Wolgaregion) sowie im kasachischen Altai ausgewählt. Aus den genannten Regionen wurden menschliche Individuen selektiert, die in die zweite Hälfte des 4. Jahrtausends v. Chr., in das 3. sowie das 1. Jahrtausend v. Chr. datieren, und den äneolithischen Steppenkulturen, den bronzezeitlichen Jamnaja- und Katakombengrabkulturen sowie Kulturgruppen aus der skythischen Periode zugerechnet werden. An ihren Zähnen und Knochen wurden Multi-Isotopenanalysen, genauer $^{87}Sr/^{86}Sr$-, $\delta^{18}O$-, $\delta^{15}N$- und $\delta^{13}C$-Analysen, durchgeführt. Neben der Evaluation der Ergebnisse für die einzelnen Fundorte und dem Vorschlag möglicher Mobilitäts- und Ernährungsmuster dieser Gemeinschaften, stand die Fragestellung im Fokus, ob sich im Zusammenhang mit Innovationsprozessen eine erhöhte Mobilität feststellen lässt, wofür die Zeit vor und nach ca. 3000 v. Chr. auf mögliche Unterschiede in den Verteilungen der Isotopenverhältnisse untersucht wurde. In Zusammenhang mit der Jamnajakultur fand ungefähr an der Wende vom 4. zum 3. vorchristlichen Jahrtausend ein Übergang zu einer auf Rinder spezialisierten Viehhaltung statt und Fortbewegungsmittel wie Wagen bzw. deren Bestandteile wurden vermehrt in den Gräbern der frühbronzezeitlichen Bevölkerung deponiert. Zudem spricht ein weiträumig kohärentes Bestattungsritual im Nordpontikum und den daran angrenzenden Regionen für weitreichende kulturelle Kontakte. Paläoklimatische Untersuchungen machen außerdem für den Zeitraum

ab dem Ende des 4. einen Wandel in den klimatischen Verhältnissen wahrscheinlich, der mit einem Aridisierungsprozess im folgenden 3. Jt.v. Chr. einherging. All dies sind Gründe, die zu Änderungen in der Lebensweise geführt haben könnten, möglicherweise in Verbindung mit erhöhter Mobilität. Als Vergleichsbasis für das 4. und 3. Jahrtausend dienten Proben, die in das 1. Jt.v. Chr. datieren, denn für diese Zeit gibt es nicht nur archäologische sondern auch schriftliche Quellen, die von einer erhöhten Mobilität der skythischen Gemeinschaften und kulturell verwandter Stämme zeugen.

Während Kapitel 1 einer kurzen Projektskizze sowie der chronologischen und kulturellen Einordnung der Studie dient, folgt in Kapitel 2 eine Charakterisierung der für diese Studie relevanten archäologischen Kulturen sowie eine Übersicht über die angewandten Methoden und die Wahl des Probenmaterials. Kapitel 3 ist der Vorstellung der Fundorte gewidmet, die die Proben für die stabilen Isotopenanalysen lieferten. Die Selektion der Fundorte, die nicht in den Händen der Verfasserin lag, sollte einen repräsentativen Querschnitt durch Raum und Zeit bieten. Bedauerlicherweise wurde nicht auf das Vorhandensein statistisch relevanter Probenmengen geachtet. Zudem lagen von keinem Fundort einheitliche Verteilungen von Alters- und Geschlechtsgruppen sowie chronologischen Perioden vor, Umstände, die eine Evaluation der Analyseergebnisse erheblich beeinträchtigten.

Die eigentliche Untersuchung war in die beiden großen Teilbereiche Mobilität und Migration sowie Ernährung gegliedert, welche aufgrund unterschiedlicher Materialbasen als zwei nur bedingt miteinander verbundene Studien angesehen werden können. Die Untersuchung zu Mobilität und Ernährung beinhaltete die Auswertung der aus dem Zahnschmelz von 142 Individuen gewonnenen Daten unter Anwendung der Strontium- ($^{87}Sr/^{86}Sr$) und Sauerstoffisotopenanalyse ($\delta^{18}O$). Die Anwendung von Kohlenstoff- ($\delta^{13}C$) und Stickstoffisotopenanalysen ($\delta^{15}N$) am Knochenmaterial 54 menschlicher Individuen von ausgewählten Fundorten aus dem West- und dem Nordpontischen Raum sowie dem Kubangebiet ermöglichte zudem einen interregionalen diachronen Vergleich zum Ernährungsverhalten.

In der archäologischen Forschung werden Mobilitätstheorien zwar häufig erwähnt, nur sporadisch finden sie jedoch tatsächlich Eingang in die Evaluation des Fundmaterials. Auch in der vorliegenden Studie erwies es sich als schwierig, die zu Beginn des Kapitels 4 vorgestellten Theorien anzuwenden, da eine Reihe von Unsicherheitsfaktoren vorliegen: Die kulturellen Grenzen der äneolithischen Steppenkulturen und der Regionalgruppen von Jamnaja- und Katakombengrabkulturen sind verhältnismäßig vage und werden häufig diskutiert. Die wirtschaftlichen Grundlagen dieser Kulturen implizieren ebenfalls Unsicherheiten. So ist zwar sicher, dass eine auf Rinder basierende Viehhaltung die dominierende ökonomische Grundlage bildete, mit der ein gewisser Grad an Mobilität verbunden war, ungewiss bleibt jedoch, in welchem Maße eine solche Mobilität vorlag. Ebenso sind die Mobilitätsradien und -ausrichtungen unbekannt, was unter anderem durch die wenigen gegrabenen Siedlungen begründet ist. Einige Siedlungen implizieren eine temporäre, saisonale Nutzung wie z. B. in der Region nordwestlich des Kaspischen Meeres, andererseits liegen auch Hinweise für permanente oder längerfristig genutzte Siedlungen vor, so z. B. am Unteren Dnjepr. Es fehlen jedoch prägnante Indikatoren für mögliche Mobilitätszyklen, wie z. B. zirkuläre oder an Ressourcen orientierte Wanderungswege. Des Weiteren stellt sich die Frage nach der Relevanz einer Referenzprobennahme in der Umgebung eines Grabhügels, für den ungeklärt ist, inwieweit dieser Platz deckungsgleich mit dem letzten Aufenthaltsort von auf irgendeine Weise mobil lebenden Gemeinschaften ist.

Die Kombination aus Strontium- und Sauerstoffisotopenanalysen, welche von verschiedenen Faktoren abhängen, ermöglichte trotz einiger Überlappungen eine isotopenchemische Differenzierung der meisten Mikroregionen und vereinfachte so die Identifizierung von Ausreißern. Die Ergebnisse der Strontiumisotopenanalyse variierten und zeigten auf der einen Seite sehr einheitliche Isotopen-

verhältnisse der menschlichen Individuen eines Fundortes, wie z. B. in Benkovski (Bulgarien), Nevskoe (Ukraine) und Olennij (Russland), während aus anderen Fundorten eine große Variabilität in den $^{87}Sr/^{86}Sr$-Werten vorlag, z. B. in Ovčarci (Bulgarien), Kirovograd (Ukraine) und an den Fundorte aus dem Mittleren Wolgagebiet (Russland). Die Ergebnisse der Sauerstoffisotopenanalyse stimmten mit diesen nur bedingt überein. Fundorte, die hinsichtlich ihrer $^{87}Sr/^{86}Sr$-Werte wenig bemerkenswert waren, lieferten teilweise eine große Variabilität in ihren $\delta^{18}O$-Werten, so z. B. in Vinogradnoe und Nevskoe (Ukraine), während Fundorte mit heterogenen $^{87}Sr/^{86}Sr$-Ergebnissen hinsichtlich $\delta^{18}O$ nur geringfügig variierten, z. B. in Kirovograd (Ukraine). Erst die Kombination der beiden Methoden ermöglichte in vielen Fällen die Identifizierung von Mobilitätsmustern. Jedoch kann nicht definitiv geklärt werden, ob die Unterschiede mit der variierenden Datenbasis oder durch tatsächlich größere Mobilitätsradien begründet werden können, da verhältnismäßig homogene Isotopenverhältnisse mehrfach mit Kurganen korrelierten, die von nur einer Kultur belegt wurden, so z. B. in Nevskoe (Ukraine), Olennij und Suchaja Termista II (Russland), während weit streuende Isotopenresultate oftmals mit einem diachron belegten Fundplatz einhergingen, z. B. in Kirovograd und Pesčanka (Ukraine). Es liegen jedoch auch Gegenbeispiele vor. Unterschiedliche Strategien bei der Referenzprobenauswahl erschwerten einen intra- und interregionalen Vergleich. Unter Vernachlässigung der variierenden Vertrauensbasen konnte jedoch vorgeschlagen werden, dass die Ergebnisse der äneolithischen und jamnajazeitlichen Proben in den westlichen Untersuchungsregionen weiter streuen als die in anderen Gebieten. Nur wenig Variation konnte für die Frühe Katakombengrabkultur konstatiert werden. Die Ergebnisse suggerieren einen potentiellen Wechsel in den Isotopenmustern, der möglicherweise mit dem einsetzenden Aridisierungsprozess und bzw. oder einem ökonomischen Wandel am Ende des 4. Jahrtausends v. Chr. in Verbindung steht. Für herausstechende Individuen, wie z. B. solche, die mit einem Wagen bestattet wurden, konnte isotopenchemisch kein erhöhter Mobilitätsgrad nachgewiesen werden.

Die relativ homogenen $^{87}Sr/^{86}Sr$- und $\delta^{18}O$-Daten der skythenzeitlichen Proben aus dem Nordpontikum können entweder als Nachweis eingeschränkter Ortswechsel interpretiert werden oder als Beweis dafür angesehen werden, dass die geringen geologischen und klimatischen Unterschiede in eine begrenzte isotopenchemische Variabilität resultieren. Einheitliche Mobilitäts- und Ernährungsmuster auf Basis einer zusammengehörigen Siedlungsgemeinschaft erscheinen aufgrund des Vorhandenseins mehrerer Fundorte unwahrscheinlich. Eine erhöhte Mobilität, die möglicherweise mit Transhumanz in Verbindung gebracht werden kann, deutete sich durch die größeren $^{87}Sr/^{86}Sr$- und $\delta^{18}O$-Spannen und Standardabweichungen der skythenzeitlichen Menschen und Tiere aus dem kasachischen Altaigebirge an. Auch die Isotopenverteilungen in den Tierzähnen einer in Kapitel 5 diskutierten dreifachen Rinderdeponierung von Zauschwitz (Deutschland), die der Kugelamphorenkultur zugeordnet wird und damit zeitliche und wirtschaftliche Parallelen zur Jamnajakultur aufweist, sprechen zumindest teilweise für das Praktizieren von Transhumanz. In diesem Zusammenhang erbrachten zusätzliche $^{87}Sr/^{86}Sr$-Laserablationen an diesen Zähnen einen beeindruckenden Mehrwert hinsichtlich des Nachweises von regulärer Mobilität.

Migrationen ganzer Gemeinschaften der äneolithischen und frühbronzezeitlichen Steppenkulturen in die Regionen westlich und südwestlich des Verbreitungsgebietes lassen sich auf der vorhandenen Datenbasis mit Hilfe von Strontium- und Sauerstoffisotopenanalysen weder zweifelsfrei bestätigen noch eindeutig dementieren. Einige Individuen in jamnajazeitlichen Hügelgräbern in Ungarn und möglicherweise ebenso die weit verteilten und partiell mit den Erwartungswerten für das Nordpontikum übereinstimmenden Isotopenverhältnisse einiger Individuen in den frühbronzezeitlichen Kurga-

nen Bulgariens, sprechen in Kombination mit dem archäologischen Befund jedoch sehr wahrscheinlich für die Einwanderung von Individuen. Dagegen wurden suggerierte Migrationen anderer Individuen, für die ebenfalls ein fremdes Bestattungsritual nachgewiesen ist, welches Charakteristika mit den im Nordpontikum ansässigen Kulturen aufweist, isotopenchemisch nicht bestätigt. Aufgrund der relativ geringen Datenbasis und der Tatsache, dass die einheimischen Bestattungsrituale nur bedingt archäologisch charakterisiert sind, müssen jedoch weitere Analysen abgewartet werden, die die vorläufigen Interpretationen bestätigen oder revidieren werden.

Zusätzlich zu den Untersuchungen zu Mobilität und Migration wurden für eine Studie zur Rekonstruktion der Ernährung Kohlenstoff- und Stickstoffisotopenanalysen an menschlichem Skelettmaterial, genauer an 53 menschlichen Knochen und acht Zähnen, angewandt. Das Probenmaterial stammte aus drei Fundorten in Bulgarien, vier Fundplätzen in der Ukraine und einem Fundort im russischen Kubangebiet. Statistische Tests bezeugten eine positive Korrelation zwischen $\delta^{13}C$ und $\delta^{15}N$, die zudem mit der geographischen Lage und den Klimaverhältnissen an den Fundorten korreliert. Eine Ernährung auf C_3-Pflanzenbasis bildete die Grundlage aller untersuchten Individuen, wobei sich die Daten der bulgarischen menschlichen Individuen deutlich von denen in der Ukraine und im Kubangebiet unterschieden. Eine Verschiebung um 3 ‰ in $\delta^{15}N$ zeigte sich zwischen Herbivoren von bulgarischen und ukrainischen Fundorten und solchen in Südrussland sowohl in Vergleichsstudien als auch in den wenigen Faunenreferenzen, die im Rahmen dieser Studie untersucht werden konnten. Diese Verschiebung kann mit unterschiedlichen klimatischen Verhältnissen erklärt werden. In Übereinstimmung mit früheren Studien, in denen leichte stabile Isotope auf prähistorische menschliche Individuen im Westeurasischen Steppengürtel angewandt wurden, kann vorgeschlagen werden, dass Fisch und andere Süßwassertiere ein zusätzlicher Bestandteil der Ernährung der äneolithischen und bronzezeitlichen Bevölkerung in diesen Regionen war, während die $\delta^{13}C$- und $\delta^{15}N$-Isotopenverhältnisse der bulgarischen Individuen in dieser Studie keinen Hinweis auf einen erhöhten Verzehr von Süßwasserressourcen gaben. Dagegen lassen die Isotopensignaturen der frühbronzezeitlichen Individuen in dieser Region auf einen nicht unwesentlichen Einfluss von C_4-Pflanzen schließen. Dies könnte als Indiz für den Anbau von C_4-Pflanzen wie z. B. Hirse gedeutet werden. Diese Pflanzen sind im Nordpontikum für das Äneolithikum und die frühe Bronzezeit nicht sicher belegt und ihr Anbau spielt erst ab der Späten Bronzezeit und in der folgenden Eisenzeit eine größere Rolle. Statistische Tests konnten aufgrund der vorliegenden Datenbasis lediglich mit großen Einschränkungen durchgeführt werden. Obwohl keine einheitliche chronologische Tendenz vorlag, konnten Unterschiede zwischen den Individuen der Jamanja- und der Frühen Katakombengrabkultur und in Vinogradnoe zudem zwischen Früher und Entwickelter Katakombengrabkultur erkannt werden. Marginale Differenzen ließen die $\delta^{13}C$- und $\delta^{15}N$-Isotopenverhältnisse von Kindern und Erwachsenen erkennen, welche auf eine fleisch- oder fischreichere Ernährung schließen lassen, geschlechtsspezifische Unterschiede lagen dagegen nicht vor. Zusammenfassend lässt sich sagen, dass die großräumig angelegte Untersuchung das Erkennen von Ernährungsunterschieden in und zwischen den einzelnen Regionen des Untersuchungsgebietes ermöglichte. Die dominierende Nahrungsgrundlage der äneolithischen, früh- und mittelbronzezeitlichen Steppenbevölkerung bildeten C_3-Pflanzen, Herbivoren, die sich von diesen ernährten, und die Produkte dieser Tiere, gleichwohl werden aber auch Süßwasserprodukte eine Rolle gespielt haben. Die Unterschiede in den $\delta^{13}C$- und $\delta^{15}N$- Isotopenverhältnissen der nord- und westpontischen Individuen lassen sich zum Teil mit variierenden klimatischen Bedingungen und unterschiedlichem Bewaldungsgrad erklären. Zudem ist ein unterschiedlich großer Einfluss von Süßwasserressourcen wahrscheinlich. Für eine fundierte Aussage zu den Ernährungsgewohnheiten der diskutierten archäologischen

Gruppen bedarf es jedoch einer Erweiterung der Probenmenge an menschlichen Individuen als auch an der lokalen Fauna und infolgedessen der Rekonstruktion eines ausgedehnten Nahrungsnetzes, welches die Grundlage für *Mixing models* bilden kann.

Bereits zu Beginn des Projektes zeichnete sich ab, dass die Anwendung von Multi-Isotopenanalysen auf ein räumlich und zeitlich extrem weit gefasstes Gebiet diffizil werden würde, und es ist zwingend notwendig eine Beprobungsstrategie zu verfolgen, die trotz dieses Rahmens denselben Qualitätsanforderungen wie in Untersuchungen von einzelnen Fundorten folgt. Statistisch relevante Probenmengen menschlicher Individuen, aber auch eine profunde Untersuchung möglicher Nahrungs- und Trinkwasserquellen sind erforderlich um fundierte Aussagen treffen zu können. Daher empfiehlt sich anstelle einer regellosen Probenselektion die Auswahl weniger Grabhügel an geologisch und klimatisch verheißungsvollen Plätzen, die auf statistisch relevanter Datenbasis eine diachrone Beprobung menschlicher Individuen ermöglichen. Nicht weniger wichtig ist eine detaillierte isotopenchemische Charakterisierung der näheren Umgebung. Auf der vorliegenden Datenbasis konnte gezeigt werden, dass das Arbeitsgebiet isotopenchemisch differenzierbar ist, und obwohl mit dem vorhandenen Probenmaterial nur vorläufige Aussagen gemacht und wahrscheinliche Tendenzen angesprochen werden konnten, bietet die Untersuchung einen extrem breit gefächerten Grundstock an Analysedaten, auf den zukünftige Studien aufbauen können.

Данное исследование объединило методы археологии и естественных наук с целью освещения поведения населения западноевразийских степей в отношении мобильности, а также характера его питания в период с 3500 по 300 гг. до н. э. Речь шла об одном из подпроектов исследовательской группы A II *Spatial effects of technological innovations and changing ways of life* в рамках междисциплинарного научно-исследовательского проекта *Topoi*. С этой целью были выбраны репрезентативные микрорегионы, а также отдельные местонахождения в Западном Причерноморье (в Болгарии), Карпато-Балканском регионе (в Венгрии), Северном Причерноморье (в южной части центральной Украины и в восточной Украине), в России (на Кубани, в Северо-Восточном Прикаспие и в Среднем Поволжье), а также в казахстанской части Алтая. Из названных регионов были отобраны человеческие индивиды, которые датируются второй половиной IV, III и I тыс. до н. э. и принадлежат к энеолитическим степным культурам, ямной и катакомбной культурам бронзового века, а также культурным группам, относящимся к скифскому периоду. На их зубах и костях были проведены мульти-изотопные анализы, а именно анализы изотопов стронция $^{87}Sr/^{86}Sr$, кислорода $\delta^{18}O$, азота $\delta^{15}N$ и углерода $\delta^{13}C$. Вторым центральным вопросом, наряду с разбором и оценкой результатов, полученных для отдельных местонахождений, и предложением проекта реконструкции возможных поведенческих моделей этих сообществ в отношении мобильности и питания, был вопрос о том, возможно ли ввиду инновационных процессов констатировать повышенную мобильность. Для решения этой задачи были исследованы периоды до и после 3000 г. до н. э. с целью выявления возможных различий в распределениях соотношений изотопов. В связи с ямной культурой приблизительно на рубеже IV-III тыс. до н. э. произошёл переход к животноводству, специализированному на содержании крупного рогатого скота, и в погребения населения раннего бронзового века стали чаще помещать такие средства передвижения, как повозки или их составные части. К тому же сходный погребальный обряд на значительной территории Северного Причерноморья и прилегающих к нему регионов свидетельствует об обширных культурных контактах. Кроме этого, исходя из палеоклиматических исследований,

вероятны изменения климатических условий в период начиная с IV. тыс. до н. э., которые сопровождались процессом аридизации в последующем III тыс. до н. э. Всё перечисленное является причинами, которые могли повлечь за собой изменение образа жизни, связанного, возможно, с повышенной мобильностью. Основой для сравнения послужили образцы, датируемые I тыс. д Сн. э., так как для этого времени имеются не только археологические, но и письменные источники, свидетельствующие о повышенной мобильности скифских сообществ и культурно им родственных племён.

В то время как глава 1 служит краткому описанию проекта, а также определению хронологических и культурных рамок исследования, в главе 2 представлены существенные для этого исследования археологические культуры, а также даны обзор применённых методов и пояснение принципов отбора материала для анализов. Глава 3 посвящена ознакомлению с местонахождениями, из которых были взяты образцы для анализов стабильных изотопов. Отбор местонахождений, на который автор исследования не имела возможности оказать влияние, должен был предоставить репрезентативный обзор во времени и пространстве, хотя, к сожалению, при этом не была принята во внимание необходимость наличия статистически существенных количеств образцов. Кроме этого, ни для одного из местонахождений не имеется равномерного распределения возрастно-половых групп, а также хронологических периодов, что усложняет обобщение полученных результатов.

Само исследование было поделено на две больших подчасти, а именно “мобильность и миграция” и “палеодиета”, которые лишь условно могут рассматриваться как два связанных друг с другом исследования, так как их основополагающие материальные базы различны. Исследование мобильности и питания включало в себя анализ данных, полученных из зубной эмали 142 индивидов, применяя анализ изотопов стронция ($^{87}Sr/^{86}Sr$) и кислорода ($\delta^{18}O$). Применение анализов изотопов углерода ($\delta^{13}C$) и азота ($\delta^{15}N$) к остеологическому материалу от 54 человеческих индивидов из избранных местонахождений западно- и северопричерноморского региона, а также Кубани дало возможность провести межтерриториальные диахронные сравнения характера питания.

Несмотря на то что теории мобильности в археологических исследованиях и упоминаются часто, они всё же редко принимаются во внимание при обобщающем анализе археологического материала. И в данном исследовании оказалось сложным применить представленные в начале главы 4 теории, так как присутствовал ряд факторов, влияющих на достоверность. Культурные границы степных энеолитических культур и региональных групп ямной и катакомбной культур сравнительно неопределённые и часто бывают предметом дискуссий. Также таит неясности экономическая основа ямной и катакомбной культур. Хотя и достоверно известно, что преобладающим экономическим основанием этих культур было животноводство, специализирующееся на крупном рогатом скоте, с чем была связана определённая степень мобильности, всё же остаётся неясным, в какой мере эта мобильность проявлялась. Также неизвестны радиусы и направления передвижений, причиной чего, в частности, является малое количество раскопанных поселений. Для некоторых поселений можно предположить временное, сезонное использование, с другой стороны, есть признаки, указывающие на бывшие постоянно или на протяжении более длительного периода в использовании поселения, как, например, в Нижнем Поднепровье. Однако отсутствуют выразительные индикаторы возможных циклов передвижений, как, например, циркулярные или ориентирующиеся на ресурсы пути миграций. Следующим вопросом является вопрос о том, насколько существен контрольный замер в окрестностях кургана, так как не выяс-

нено, является ли это место тождественным с местом последнего пребывания сообществ, живущих в какой-либо мере мобильно.

Сочетание анализов изотопов стронция и кислорода, которые не зависимы друг от друга, а зависят от различных факторов, дало возможность, несмотря на некоторые наложения, провести изотопно-химическое дифференцирование большинства микрорегионов и облегчило таким образом распознавание экстремальных значений. Результаты анализа изотопов стронция варьировали и проявили, с одной стороны, очень единообразные соотношения изотопов для человеческих индивидов одного местонахождения, как, например, Бенковски (Болгария), Невского (Украина) и Оленнего (Россия), в то время, как для других местонахождений – например, Овчарци (Болгария), Кировограда (Украина) и местонахождений Среднего Поволжья (Россия) – было налицо широкое варьирование значений $^{87}Sr/^{86}Sr$. Результаты анализа изотопов кислорода соответствовали им лишь в ограниченной мере. Местонахождения, которые были мало примечательными относительно значений $^{87}Sr/^{86}Sr$, показали отчасти широкую вариативность в их $\delta^{18}O$-значениях, как, например, Виноградное и Невское (Украина), в то время, как местонахождения с гетерогенными результатами по $^{87}Sr/^{86}Sr$ варьировали относительно $\delta^{18}O$ незначительно, например, Кировоград (Украина). Лишь сочетание обоих методов дало во многих случаях возможность распознать модели мобильности. Однако определённо не может быть выясненым, могут ли варьирующая база данных или действительно бóльшие радиусы передвижений являться причиной этих различий, так как сравнительно гомогенные соотношения изотопов во многих случаях коррелируют с теми курганами, которые содержат погребения лишь одной культуры, как, например, в Невском (Украина), Оленнем и в могильнике Сухая Термиста II (Россия), в то время, как широко разбросанные результаты анализов изотопов часто были связаны с местонахождением, содержащим погребения разновременных культур, например, в Кировограде и Песчанке (Украина). Но есть и примеры, свидетельствующие об обратном. Различные стратегии выбора материала для контрольных замеров усложняли внутри- и межрегиональное сопоставление. Не принимая во внимание то обстоятельство, что образцы для контрольных замеров были различными в отношении степени полагаемого на них доверия, можно было предположить, что результаты анализов образцов периодов энеолита и раннего бронзового века в западной части территории исследования разбросаны шире, чем в других областях. Лишь незначительные вариации могли быть констатированы для ранней катакомбной культуры. Эти результаты наводят на мысль о возможном изменении моделей изотопов на переходе к раннему этапу катакомбной культуры, которое, как можно предположить, связано с начинающимся процессом аридизации и/или экономическими преобразованиями в конце IV тыс. до н. э. Для выделяющихся личностей, например, погребённых с повозкой, изотопно-химически не была доказана повышенная степень мобильности. Сравнительно однородные данные по $^{87}Sr/^{86}Sr$ и $\delta^{18}O$ для образцов скифского периода из Северного Причерноморья могут быть интерпретированы или как свидетельство относительно ограниченной перемены местожительства, или же как доказательство того, что из незначительных геологических и климатических различий следует ограниченная изотопно-химическая вариабельность. Объяснением таких единообразных моделей мобильности и питания не может быть сплочённость сообщества поселений, так как анализы были проведены для образцов из различных местонахождений. Повышенная мобильность, которая, возможно, связана с транзюмансом, вырисовалась из широких промежутков $^{87}Sr/^{86}Sr$ и $\delta^{18}O$, а также высоких стандартных отклонений для людей и животных скифского времени из казахстанского Алтая. Распределения изотопов в зубах животных рассматриваемого в главе 5 тройного трупоположения

быков из Цаушвитца (Германия), которое относят к культуре шаровидных амфор, проявляющей хронологические и экономические параллели к ямной культуре, свидетельствуют по меньшей мере частично о практицировании транзюманса. Дополнительные анализы $^{87}Sr/^{86}Sr$ посредством лазерной абляции на тех же зубах предоставили впечатляющие добавочные результаты относительно доказательства обыденной мобильности.

Миграции степных культур периодов энеолита и раннего бронзового века в регионы к западу и юго-западу от области их распространения не могут быть на основании имеющихся данных с помощью анализов изотопов стронция и кислорода ни безусловно подтверждены, ни однозначно отвергнуты. Некоторые погребённые в курганах ямного времени в Венгрии, а, возможно, также и соотношения изотопов некоторых индивидов из курганов раннего бронзового века в Болгарии, показатели которых широко разбросаны и частично соответствуют ожидаемым для Северного Причерноморья соотношениям, свидетельствуют в сочетании с археологическим контекстом с большой вероятностью о переселении индивидов в эти регионы. С другой стороны, предположение о том, что миграции могли иметь место, не подтвердились с помощью изотопно-химических анализов для других индивидов с чужеродным ритуалом погребения, которому присущи черты, характерные для культур Северного Причерноморья. В силу относительно небольшой базы данных и того обстоятельства, что локальным погребальным обрядам дана лишь недостаточная археологическая характеристика, необходимо всё же дождаться дальнейших анализов, которые позволят подтвердить или исправить предварительные интерпретации. Помимо изучения мобильности и миграций, анализы изотопов углерода и азота были применены на человеческом скелетном материале, а точнее 53 человеческих костях и восьми зубах, для реконструкции питания. Материал для анализов происходил из трёх местонахождений в Болгарии, четырёх местонахождений в Украине и одного на Кубани в России. Статистические тесты удостоверили позитивную корреляцию между показателями $\delta^{13}C$ и $\delta^{15}N$, и эти показатели в свою очередь коррелируют с географическим положением и климатическими условиями по месту находки. Питание на основании C3-растений составляло основу диеты всех исследованных индивидов, причём данные, полученные для человеческих индивидов Болгарии, чётко отличались от данных для образцов из Украины и Кубани. Смещение показателей $\delta^{15}N$ на 3 ‰ обнаружено при сопоставлении травоядных из болгарских и украинских местонахождений с травоядными юга России как в сравнительных исследованиях, так и в немногих ссылках на фауну, которые могли быть рассмотрены в рамках этого исследования. Это смещение можно объяснить различными климатическими условиями. В соответствии с предыдущими исследованиями, в которых анализ лёгких стабильных изотопов был применён к доисторическим человеческим индивидам западноевразийского степного пояса, можно предположить, что рыба и другие пресноводные животные были дополнительной составляющей частью диеты энеолитического населения и населения бронзового века этих регионов, в то время, как соотношения изотопов $\delta^{13}C$ и $\delta^{15}N$ для индивидов из местонахождений Болгарии не засвидетельствовали в данном исследовании об употреблении в пищу пресноводных рессурсов. Напротив, изотопные шифры населения раннего бронзового века этого региона позволяют сделать вывод о немаловажном влиянии C4-растений. Это могло бы быть свидетельством выращивания C4-растений, например, проса, которые для Северного Причерноморья периодов энеолита и раннего бронзового века достоверно не засвидетельствованы, и их выращивание имеет бóльшее значение лишь начиная с позднего бронзового, а также в последующем железном веке.

Статистические тесты могли быть проведены на основании имеющейся в наличии базы даных лишь с большими ограничениями. Хотя единообразной хронологической тенденции и не наблюдалось, могли быть распознаны различия между индивидами ямной и раннекатакомбной культуры, а в Виноградном к тому же и между представителями ранней и развитой фазы катакомбной культуры. Соотношения изотопов $\delta^{13}C$ и $\delta^{15}N$ детей и взрослых позволили обнаружить лишь незначительные различия, что позволяет сделать вывод о преобладании мяса или рыбы в рационе, в то время как гендерных различий не наблюдалось. Широкомасштабно спланированное исследование позволило распознать в границах его территории внутри- и межрегиональные различия в рационе питания, причиной которых могут быть климатические изменения. Преобладающую основу рациона различных групп степного населения энеолита, раннего и среднего бронзового века составляли C3-растения, травоядные животные, питающиеся этими растениями, а также продукты от этих животных. В то же время значимыми могли быть и пресноводные продукты. Различия в соотношениях изотопов $\delta^{13}C$ и $\delta^{15}N$ северо- и западнопричерноморских индивидов можно частично объяснить изменяющимися климатическими условиями, так как не только люди, но и травоядные животные обнаруживают различные соотношения изотопов. Кроме того, вероятно, что влияние пресноводных рессурсов было различным по значимости. Для обоснованного утверждения о привычках питания обсуждаемых археологических групп необходимыми являются расширение количества образцов для анализов как от людей, так и от локальных животных, и вследствие этого реконструкция расширенной сети питания, которые могут сформировать основу для моделей смешения изотопов (*Mixing models*).

Уже к началу работы над проектом обозначилось, что применение мульти-изотопных анализов для крайне обширной территории с очень широким хронологическим диапазоном может быть связано со сложностями. Настоятельно необходимо придерживаться такой стратегии отбора и анализа образцов, которая, несмотря на широкие рамки исследования, отвечает тем же требованиям к качеству, что и при проведении анализов для отдельных местонахождений. Для обоснованных утверждений необходимы статистически существенные количества образцов от человеческих индивидов, а также основательное исследование возможных источников питания и питьевой воды. Поэтому вместо несистематического отбора проб рекомендуется выбрать небольшое количество курганов, расположенных в геологически и климатически многообещающих местах, которые позволили бы осуществить диахронический анализ человеческих индивидов на статистически существенном основании. Не менее важной является подробная изотопно-химическая характеристика ближайших окрестностей. На основе имеющихся данных представилось возможным показать, что территория исследования дифференцируема с изотопно-химической точки зрения. Несмотря на то, что на основе имеющихся в наличии образцов для испытаний могут быть сделаны лишь предварительные высказывания и рассмотрены вероятные тенденции, исследование предоставляет крайне обширный фундамент данных анализов, на основе которых могут быть построены дальнейшие исследования.

Translation: N. Chub

8 Bibliography

Primary literature in Russian is not listed in the bibliography.

Adams et al., 1978
W. Y. Adams/D. P. van Gerven/R. S. Levy, The retreat from migrationism. Annual Revue of Anthropology 7, 1978, 483–532.

Alekseev, 2007
A. Yu. Alekseev, Skythische Könige und Fürstenkurgane. In: W. Menghin/H. Parzinger (Eds.), Im Zeichen des goldenen Greifen. Königsgräber der Skythen (München/London/New York 2007) 242–255.

Alekseev et al., 2001
A. Yu. Alekseev/N. A. Bokovenko/Yu. Boltrik/K. A. Chugunov/G. Cook/V. A. Dergachev/ N. Kovalyukh/G. Possnert/J. van der Plicht/E. M. Scott/A. Semeetsov/V. Skripkin/S. Vasiliev/G. Zaitseva, Chronology of Eurasian Scythian antiquities born by new archaeological and ^{14}C data. Radiocarbon 43, 2001, 1085–1107.

Alexandrov, 2011
St. Alexandrov, Prehistoric barrow graves between the Danube and the Balkan range. Stratigraphy and relative Chronology. In: E. Borgna/S. Müller-Celka (Eds.), Ancestral landscapes: Burial mounds in the Copper and Bronze ages (Central and Eastern Europe – Balkans – Adriatic – Aegean, 4th–2nd millennium BC). International Conference, Udine/Italy, May 15th–18th 2008. Travaux de la Maison de l'Orient et de la Méditerranée 58 (Lyon 2011) 307–320.

Alt, 2010
K. W. Alt, Grenzüberschreitungen – Wissenschaft im Dialog um die Vergangenheit. In: H. Meller/K. W. Alt (Eds.), Anthropologie, Isotopie und DNA – biografische Annäherung an namenlose vorgeschichtliche Skelette? Tagungen des Landesmuseums für Vorgeschichte Halle 3 (Halle (Saale) 2010) 9–16.

Ambrose, 1986
S. H. Ambrose, Stable carbon and nitrogen isotope analysis of human diet in Africa. Journal of Human Evolution 15, 1986, 707–731.

Ambrose, 1991
S. H. Ambrose, Effects of diet, climate and physiology on nitrogen isotope abundances in terrestrial foodwebs. Journal of Archaeological Science 18, 1991, 293–317.

Ambrose, 1993
S. H. Ambrose, Isotopic analysis of paleodiets. Methodological interpretative considerations. In: M. K. Sandford (Ed.), Investigations of ancient human tissue. Chemical analysis in anthropology (Langhorne, PA 1993) 59–130.

Ambrose/DeNiro, 1986
S. H. Ambrose/M. J. DeNiro, Reconstruction of African human diet using bone collagen carbon and nitrogen isotope ratios. Nature 319, 1986, 321–324.

Ambrose/DeNiro, 1987
S. H. Ambrose/M. J. DeNiro, Bone nitrogen isotope composition and climate. Nature 324, 1987, 201.

Ambrose/Norr, 1993
S. H. Ambrose/L. Norr, Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In: J. B. Lambert/G. Grupe (Eds.), Prehistoric human bone – Archaeology at the molecular level (Berlin/Heidelberg 1993) 1–38.

Ammerman/Cavalli-Sforza, 1973
A. J. Ammerman/L. L. Cavalli-Sforza, A population model for the diffusion on early farming in Europe. In: C. Renfrew (Ed.), The explanation of culture change: Models in prehistory (London 1973) 243–358.

Ammerman/Cavalli-Sforza, 1979
A. J. Ammerman/L. L. Cavalli-Sforza, The wave of advance model for the spread of agriculture in Europe. In: C. Renfrew/K. L. Cooke (Eds.), Transformations. Mathematical approaches to culture change (New York 1979) 275–294.

Ammerman/Cavalli-Sforza, 1984
A. J. Ammerman/L. L. Cavalli-Sforza, The Neolithic transition and the genetics of populations in Europe (Princeton, NJ 1984).

Anthony, 1986
D. W. Anthony, The 'Kurgan Culture', Indo-European origins, and the domestication of the horse: A reconsideration. Current Anthropology 27, 1986, 291–313.

Anthony, 1990
D. W. Anthony, Migration in Archaeology: The baby and the bathwater. American Anthropologist 92, 1990, 895–914.

Anthony, 1992
D. W. Anthony, The bath refilled: Migration in archeology again. American Anthropologist 94, 174–176.

Anthony, 1997
D. W. Anthony, Prehistoric migration as social process. In: J. Chapman/H. Hamerow (Eds.), Migrations and invasions in archaeological explanation. BAR International Series 664 (Oxford 1997) 21–32.

Anthony, 2000
D. W. Anthony, Comment on: S. Burmeister, Archaeology and migration. Approaches to an archaeological proof of migration. Current Anthropology 41/4, 2000, 554–555.

Anthony, 2004
D.W. Anthony, Bronze Age herders of the Eurasian steppes. Available online: http://www.novelguide.com/a/discover/aneu_02/aneu_02_00132.html (accessed 02. 04. 2011).

Anthony, 2007
D. W. Anthony, The horse, the wheel, and language: How Bronze Age riders from the Eurasian steppes shaped the modern world (Princeton, NJ 2007).

Anthony, 2009
D.W. Anthony, The Sintashta Genesis. The Roles of climate change, warfare, and long-distance trade. In: B. K. Hanks/K. M. Linduff (Eds.), Social complexity in Prehistoric Eurasia. Monuments, metals, and mobility (Cambridge/New York etc. 2009) 47–73.

Anthony et al., 2006
D. W. Anthony/D. Brown/A. Goodman/A. Kokhlov/P. Kosintsev/P. Kuznetsov/O. Mochalov/E. Murphy/D. Peterson/A. Pike-Tay/L. Popova/A. Rosen/N. Russel/A. Weisskopf, The Samara Valley Project. Late Bronze Age economy and ritual in the Russian steppes. Eurasia Antiqua 11, 2005 (2006) 395–417.

Arbos, 1923
P. Arbos, The geography of pastoral life illustrated with European examples. Geographical Review 13, 1923, 559–575.

Asch, 2005
K. Asch, The 1:5 million international geological map of Europe and adjacent areas. Bundesanstalt für Geowissenschaften und Rohstoffe. Hannover, 2005. Available online: http://www.bgr.de/karten/igme5000/igme5000.htm (accessed 30. 06. 2012).

Avanzinelli et al., 2005
R. Avanzinelli/E. Boari/S. Conticelli/L. Francalanci/L. Guarnieri/G. Perini/C. M. Petrone/S. Tommasini/M. Ulivi, High precision Sr, Nd, and Pb isotopic analyses using the new generation Thermal Ionisation Mass Spectrometer ThermoFinnigan Triton-Ti®. Periodico di Mineralogia 74/3, 2005, 147–166.

Ayliffe/Chivas, 1990
L. K. Ayliffe/A. R. Chivas, Oxygen isotope composition of the bone phosphate of Australian kangaroos: Potential as a paleoenvironmental recorder. Geochimica et Cosmochimica Acta 54, 1990, 2603–2609.

Ayliff et al., 1992
L. K. Ayliffe/A. M. Lister/A. R. Chivas, The preservation of glacial–interglacial climatic signatures in the oxygen isotopes of elephant skeletal phosphate. Palaeogeography, Palaeoclimatology, Palaeoecology 99, 1992, 179–191.

Balasse, 2003
M. Balasse, Potential biases in sampling. Design and interpretation of intra-tooth isotope analysis. International Journal of Osteoarchaeology 13, 2003, 3–10.

Balasse/Tresset, 2002
M. Balasse/A. Tresset, Early weaning of Neolithic domestic cattle (Bercy, France) revealed by intra-tooth variation in nitrogen isotope ratios. Journal of Archaeological Science 29, 2002, 853–859.

Balasse/Tresset, 2007
M. Balasse/A. Tresset, Environmental constraints on the reproductive activity of domestic sheep and cattle: What latitude for what herder? Anthropozoologica 42, 2007, 71–87.

Balasse et al., 2002
M. Balasse/S. H. Ambrose/A. B. Smith/T. D. Price, The seasonal mobility model for prehistoric herders in the south-western Cape of South Africa assessed by isotopic analysis of sheep tooth enamel. Journal of Archaeological Science 29, 2002, 917–932.

Balasse et al., 2003
M. Balasse/A. B. Smith/S. H. Ambrose/S. R. Leigh, Determining sheep birth seasonality by analysis of tooth enamel oxygen isotope ratios: The late Stone Age site of Kasteelberg (South Africa). Journal of Archaeological Science 30, 2003, 205–215.

Balasse et al., 2006
M. Balasse/A. Tresset/S. H. Ambrose, Stable isotope evidence ($\delta^{13}C$, $\delta^{18}O$) for winter feeding on seaweed by Neolithic sheep of Scotland. Journal of Zoology 270, 2006, 170–176.

Balasse et al., 2012
M. Balasse/G. Obein/J. Ughetto-Monfrin/I. Mainland, Investigating seasonality and season of birth in past herds: A reference set of sheep enamel stable oxygen isotope ratios. Archaeometry 54/2, 2012, 349–368.

Barkova, 2007
L. L. Barkova, Die Fürstengräber der Pazyryk-Kultur. In: W. Menghin/H. Parzinger (Eds.), Im Zeichen des goldenen Greifen. Königsgräber der Skythen (München/London/New York 2007) 118–131.

Barrett et al., 2008
J. Barrett/C. Johnstone/J. Harland/W. van Neer/A. Ervynck/D. Makowiecki/ D. Heinrich/A. K. Hufthammer/I. Bødker Enghoff/C. Amundsen/J. S. Christiansen/A. K. G. Jones/A. Locker/S. Hamilton-Dyer/L. Jonsson/L. Lougas/C. Roberts/M. Richards, Detecting the medieval cod trade: A new method and first results. Journal of Archaeological Science 35, 2008, 850–861.

Bátora, 2002
J. Bátora, Contribution to the problem of 'craftsmen' graves at the end of the Aeneolithic and in the Early Bronze Age in Central, Western and Eastern Europe. Slovenská Archeológia 50.2, 2002, 179–228.

Beard/Johnson, 2000
B. L. Beard/C. M. Johnson, Strontium isotope composition of skeletal material can determine the birth place and geographic mobility of humans and animals. Journal of Forensic Sciences 45/II, 2000, 1049–1061.

Beier, 1988
H.-J. Beier, Die Kugelamphorenkultur im Mittelelbe-Saale-Gebiet und der Altmark. Veröffentlichungen des Landesmuseums für Vorgeschichte in Halle 41 (Berlin 1988).

Behrens, 1964
H. Behrens, Die neolithisch-frühmetallzeitlichen Tierskelettfunde der Alten Welt (Berlin 1964).

Behrens, 1973
H. Behrens, Die Jungsteinzeit im Mittelelbe-Saale-Gebiet. Veröffentlichungen des Landesmuseums für Vorgeschichte in Halle 27 (Berlin 1973).

Belinskii/Kalmykov, 2004
A. B. Belinskii/A. A. Kalmykov, Neue Wagenfunde aus Gräbern der Katakombengrabkultur im Steppengebiet des zentralen Vorkaukasus. In: M. Fansa/St. Burmeister (Eds.), Rad und Wagen: der Ursprung einer Innovation. Wagen im Vorderen Orient und Europa (Mainz 2004) 201–220.

Bendrey, 2011
R. Bendrey, Some like it hot: Environmental determinism and the pastoral economies of the later prehistoric Eurasian steppe. Pastoralism: Research, Policy and Practice 2001, 1:8. Available online: http://www.pastoralismjournal.com/content/1/1/8 (accessed 10.01.2012).

Bendrey et al., 2009
R. Bendrey/T. E. Hayes/M. R. Palmer, Patterns of Iron Age horse supply: An analysis of Strontium isotope ratios in teeth. Archaeometry 51/1, 2009, 140–150.

Bendrey et al., in press
R. Bendrey/S. Lepetz/A. Zazzo/M. Balasse/T. Turbat/P.-H. Giscard/D. Vella/G. I. Zaitseva/K. V. Chugunov/J. Ughetto/K. Debue/J.-D. Vigne, Nomads, horses and mobility: An assessment of geographic origins of Iron Age horses found at Tsengel Khairkhan and Baga Turgen Gol (Mongolian Altai) based on oxygen isotope compositions of tooth enamel. In: M. Mashkour/M. Beech (Eds.), Proceedings of the 9th ASWA conference, Al Ain, 2008 (in press).

Benecke, 1998
N. Benecke, Diachroner Vergleich der Pferdehaltung im Karpatenbecken und in der osteuropäischen Steppe während der vorchristlichen Metallzeiten. In: B. Hänsel/J. Machnik (Eds.), Das Karpatenbecken und die osteuropäische Steppe. Nomadenbewegung und Kulturaustausch in den vorchristlichen Metallzeiten (4000–500 v. Chr.). Südosteuropa-Schriften 20, Prähistorische Archäologie in Südosteuropa 12 (München/Rahden (Westf.) 1998) 91–98.

Benecke, 2003
N. Benecke, Iron Age economy of the Inner Asian steppe. A bioarchaeological perspective from the Talgar Region in the Ili River Valley (Southeastern Kazakhstan). Eurasia Antiqua 9, 2003, 63–84.

Benecke et al., 2007
N. Benecke/Ch. Weber/J. Burger, Die Entstehung des Hauspferdes aus Sicht der Archäozoologie und der Molekulargenetik. In: A. Wieczorek/M. Tellenbach (Eds.), Pferdestärken. Das Pferd bewegt die Menschheit. Begleitband zur Sonderausstellung in den Reiss-Engelhorn-Museen, 21. April bis 19. August 2007. Publikationen der Reiss-Engelhorn-Museen 23 (Mannheim/Mainz 2007) 33–38.

Bentley, 2006
R. A. Bentley, Strontium Isotopes from the earth to the archaeological skeleton: A review. Journal of Archaeological Method and Theory 13/3, 2006, 135–187.

Bentley/Knipper, 2005
R. A. Bentley/C. Knipper, Geographical patterns in biologically available strontium, carbon and oxygen isotope signatures in prehistoric SW Germany. Archaeometry 47/3, 2005, 629–644.

Bentley et al., 2002
R. A. Bentley/T. D. Price/J. Lüning/D. Gronenborn/J. Wahl/P. D. Fullagar, Human Migration in early Neolithic Europe. Current Anthropology 43, 2002, 799–804.

Bentley et al., 2003
R. A. Bentley/R. Krause/T. D. Price/B. Kaufmann, Human mobility at the early Neolithic settlement of Vaihingen, Germany: Evidence from strontium isotope analysis. Archaeometry 45, 2003, 481–496.

Bentley et al., 2004
R. A. Bentley/T. D. Price/E. Stephan, Determining the 'local' $^{87}Sr/^{86}Sr$ range of archaeological skeletons: A case study from Neolithic Europe. Journal of Archaeological Science 31, 2004, 365–375.

Bentley et al., 2012
R. A. Bentley/P. Bickle/L. Fibiger/G. M. Nowell/Chr. W. Dale/R. E. M. Hedges/J. Hamilton/J. Wahl/M. Francken/G. Gruppe/E. Lenneis/M. Teschler-Nicola/R.-M. Arbogast/D. Hofmann/A. Whittle, Community differentiation and kinship among Europe's first farmers. Proceedings of the National Academy of Sciences 109/24, 2012, 9326–9330.

Berg, 1959
L. S. Berg, Die geographischen Zonen der Sowjetunion II (Leipzig 1959).

Bickle/Hofmann, 2007
P. Bickle/D. Hofmann, Moving on: The contribution of isotope studies to the early Neolithic of Central Europe. Antiquity 81, 2007, 1029–1041.

Bickle/Whittle, 2013
P. Bickle/A. W. R. Whittle (Eds.), The first farmers of Central Europe: Diversity in LBK lifeways (Oxford 2013).

Bickle et al., 2011
P. Bickle/D. Hofmann/R. A. Bentley/R. Hedges/J. Hamilton/F. Laiginhas/G. Nowell/D. G. Pearson/G. Grupe/A. Whittle, Roots of diversity in a Linearbandkeramik community: Isotope evidence at Aiterhofen (Bavaria, Germany). Antiquity 85/330, 2011, 1243–1258.

Binford, 1965
L. R. Binford, Archaeological systematics and the study of culture process. American Antiquity 31, 1965, 203–210.

Bocherens/Drucker, 2003
H. Bocherens/D. Drucker, Trophic level isotopic enrichment of carbon and nitrogen in bone collagen: Case studies from recent and ancient terrestrial ecosystems. International Journal of Osteoarchaeology 13, 2003, 46–53.

Bocherens/Mariotti, 1992
H. Bocherens/A. Mariotti, Biogéochimie isotopique du carbone dans les os de mammiferes actuels et fossiles de zones froides et tempérées. Comptes Rendus de l'Académie des Sciences 315, 1992, 1147–1158.

Bocherens et al., 1994
H. Bocherens/D. B. Brinkman/Y. Dauphin/A. Mariotti, Microstructural and geochemical investigations on Late Cretaceous archosaur teeth from Alberta (Canada), Canadian Journal of Earth Sciences 3, 1994, 783–792.

Bocherens et al., 1996
H. Bocherens/P. Koch/A. Mariotti/D. Geraads/J. Jaeger, Isotopic biogeochemistry (13C, 18O) of mammalian enamel from African Pleistocene hominid sites, Palaios 11, 1996, 306–318.

Bogaard et al., 2007
A.Bogaard/T. H. E. Heaton/P. Poulton/I. Merbach, The impact of manuring on nitrogen isotope ratios in cereals: archaeological implications for reconstruction of diet and crop management practices. Journal of Archaeological Science 34, 2007, 335–343.

Bokovenko, 1995a
N. A. Bokovenko, History of studies and the main problems in the archaeology of southern Siberia during the Scythian period. In: J. Davis-Kimball/V. A. Bashilov/L. T. Yablonsky (Eds.), Nomads of the Eurasian steppes in the Early Iron Age (Berkeley, CA 1995) 255–264.

Bokovenko, 1995b
N. A. Bokovenko, Scythian culture in the Altai mountains. In: J. Davis-Kimball/V. A. Bashilov/L. T. Yablonsky (Eds.), Nomads of the Eurasian steppes in the Early Iron Age (Berkeley, CA 1995) 285–298.

Bokovenko, 2004
N. Bokovenko, Migrations of early nomads of the Eurasian steppe in a context of climatic changes. In: E. M. Scott/A. Yu. Alekseev/G. Zaitseva (Eds.), Impact of the environment on human migration in Eurasia. IV Earth and Environmental Sciences 42 (Dordrecht et al. 2004) 21–33.

Bonsall et al., 1997
C. Bonsall/R. Lennon/K. McSweeney/C. Stewart/D. Harkness/V. Boroneanț/L. Bartosiewicz/R. Payton/J. Chapman, Mesolithic and early neolithic in the iron gates: A palaeodietary perspective. Journal of European Archaeology 5, 1997, 50–92.

Bonsall et al., 2000
C. Bonsall/G. T. Cook/R. Lennon/D. Harkness/M. Scott/L. Bartosiewicz/K. McSweeney, Stable isotopes, radiocarbon and the Mesolithic–Neolithic transition in the Iron Gates. Documenta Praehistorica 27, 2000, 119–132.

Borić et al., 2004
D. Borić/G. Gruppe/J. Peters/Ž. Mikić, Is the Mesolithic–Neolithic subsistence dichotomy real? New stable isotope evidence from the Danube Gorges. Journal of European Archaeology 7, 2004, 221–248.

Borisov, 1965
A. A. Borisov, Climates of the U.S.S.R. (London 1965).

Boroffka/Mantu-Lazarovici, 2011
N. Boroffka/C.-M. Mantu-Lazarovici, Zwei Bronzesicheln der Noua – Kultur aus Poienesti: Zur Wirtschaft in den bronzezeitlichen Steppen Eurasiens. In: E. Sava/B. Govedarica/B. Hänsel (Hrsg.), Der Schwarzmeerraum vom Äneolithikum bis in die Früheisenzeit (5000–500 v. Chr.). Band 2: Globale Entwicklung versus Lokalgeschehen. Internationale Fachtagung von Humboldtianern für Humboldtianer im Humboldt-Kolleg in Chişinau, Moldawien (4.–8. Oktober 2010). Prähistorische Archäologie in Südosteuropa 27 (Rahden (Westf.) 2011) 148–165.

Bourdieu, 1993
P. Bourdieu, Sozialer Sinn. Kritik der theoretischen Vernunft (Frankfurt (Main) 1993).

Bowen, 2010
G. J. Bowen, The Online Isotope in Precipitation Calculator, Version 2.2, 2010. http://www.waterisotopes.org (last accessed 06. 02. 2012).

Bowen/Wilkinson, 2002
G. J. Bowen/B. Wilkinson, Spatial distribution of $\delta^{18}O$ in meteoric precipitation, Geology 30 (4), 2002, 315–318.

Bowen/Revenaugh, 2003
G. J. Bowen/J. Revenaugh, Interpolating the isotopic composition of modern meteoric precipitation. Water Resources Research 39 (10), 1299, 2003. DOI: 10.129/2003WR002086.

Bowen et al., 2005
G. J. Bowen/L. I. Wasenaar/K. A. Hobson, Global application of stable hydrogen and oxygen isotopes to wildlife forensics, Oecologia 143, 2005, 337–348.

Brandt et al., 2010
G. Brandt/C. Knipper/Chr. Roth/A. Siebert/K. W. Alt, Beprobungsstrategien für aDNA und Isotopenanalysen an Skelettmaterial. In: H. Meller/K. W. Alt (Eds.), Anthropologie, Isotopie und DNA – biografische Annäherung an namenlose vorgeschichtliche Skelette? Tagungen des Landesmuseums für Vorgeschichte Halle 3 (Halle (Saale) 2010) 17–32.

Britton et al., 2009
K. Britton/V. Grimes/J. Daux/M. P. Richards, Reconstructing faunal migrations using intra-tooth sampling and strontium and oxygen isotope analyses: A case study of modern caribou (*Rangifer tarandus granti*). Journal of Archaeological Science 36, 2009, 1163–1172.

Bronk Ramsey et al., 2004
C. Bronk Ramsey/T. F. G. Higham/A. Bowles/R. E. M. Hedges, Improvements to the pretreatment of bone at Oxford, Radiocarbon 46, 2004, 155–163.

Brown et al., 1960
W. A. B. Brown/P. V. Christofferson/M. Massler /M. B. Weiss, Postnatal tooth development in cattle. American Journal of Veterinary Research 21, 1960, 7–34.

Bryant/Froelich, 1995
J. D. Bryant/Ph. N. Froehlich, A model of oxygen isotope fractionation in body water of large mammals. Geochimica et Cosmochimica Acta 59, 1995, 4523–4537.

Bryant et al., 1994
J. D. Bryant/B. Luz/Ph. N. Froelich, Oxygen isotopic composition of fossil horse tooth phosphate as a record of continental palaeoclimate. Palaeography, Palaeoclimatology, Palaeoecology 107, 1994, 303–316.

Bryant et al., 1996a
J. D. Bryant/Ph. N. Froelich/W. J. Showers/B. J. Genna, Biologic and climatic signals in the oxygen isotopic composition of Eocene–Oligocene equid enamel phosphate. Palaeography, Palaeoclimatology, Palaeoecology 126, 1996, 75–89.

Bryant et al., 1996b
J. D. Bryant/Ph. N. Froelich/W. J. Showers/B. J. Genna, A tale of two quarries: Biologic and taphonomic signatures in the oxygen isotope composition of tooth enamel phosphate from modern and Miocene equids. Palaios 11, 1996, 397–408.

Budd et al., 2000
P. Budd/J. Montgomery/B. Barreiro/R. G. Thomas, Differential diagenesis of strontium in archaeological human dental tissues. Applied Geochemistry 15, 2000, 687–694.

Budd et al., 2002
P. Budd/C. Chenery/J. Montgomery/J. Evans/D. Powlesland, Anglo-Saxon residential mobility at West Heslerton, North Yorkshire, from combined O- and Sr-iso-

tope analysis. In: S. Tanner/G. Halland (Eds.), Proceedings of the 8th international conference on plasma source mass spectrometry (Durham 2002) 195–208.

Budd et al., 2003
P. Budd/C. Chenery/J. Montgomery/J. Evans, You are where you ate: Isotopic analysis in the reconstruction of prehistoric residency. In: M. Parker Pearson (Ed.), Food, culture and identity in the Neolithic and Early Bronze Age, BAR International Series 1117 (Oxford 2003) 69–79.

Budd et al., 2004
P. Budd/A. Millard/C. Chenery/S. Lucy/C. Roberts, Investigating population movement by stable isotope analysis: a report from Britain. Antiquity 78, 2004, 127–141.

Buddecke, 1981
E. Buddecke, Biochemische Grundlagen der Zahnmedizin (Berlin/New York 1981).

Bunyatyan, 2003
K. P. Bunyatyan, Correlations between Agriculture and Pastoralism in the Northern Pontic Steppe Area during the Bronze Age. In: M. Levine/C. Renfrew/K. Boyle (Eds.), Prehistoric steppe adaptation and the horse (Cambridge 2003) 269–286.

Bunjatjan/Nikolova, 2006
K. P. Bunjatjan/A. V. Nikolova, Einführung. In: K. P. Bunjatjan/E. Kaiser/A. V. Nikolova (Eds.), Bronzezeitliche Bestattungen aus dem Unteren Dneprgebiet. Schriften des Zentrums für Archäologie und Kulturgeschichte des Schwarzmeerraumes 8 (Langenweißbach 2006) 1–4.

Bunjatjan et al., 2006
K. P. Bunjatjan/E. Kaiser/A. V. Nikolova (Eds.), Bronzezeitliche Bestattungen aus dem Unteren Dneprgebiet. Schriften des Zentrums für Archäologie und Kulturgeschichte des Schwarzmeerraumes 8 (Langenweißbach 2006).

Burmeister, 1998
St. Burmeister, Ursachen und Verlauf von Migrationen – Anregungen für die Untersuchung prähistorischer Wanderungen. Studien zur Sachsenforschung 11, 1998, 19–41.

Burmeister, 2000
St. Burmeister, Archaeology and Migration. Approaches to an archaeological proof of migration. Current Anthropology 41/4, 2000, 539–553.

Burmeister, 2013
St. Burmeister, Migration – Innovation – Kulturwandel. Aktuelle Problemfelder archäologischer Investigation. In: E. Kaiser/W. Schier (Eds.), Mobilität und Wissenstransfer in diachroner und interdisziplinärer Perspektive. Topoi. Berlin Studies of the Ancient World 9 (Berlin 2013) 35–58.

Burtănescu, 1996
F. Burtănescu, Consideraţii asupra unor morminte tumulare de pe teritoriul Moldovei (perioda de tranziţie-Bronz timpuriu). Thraco-Dacica 17, 1996, 87–116.

Burton et al., 1999
J. H. Burton/T. D.Price/W. D. Middleton, Correlation of bone Ba/Ca and Sr/Ca due to biological purification of calcium. Journal of Archaeological Science 26, 609–616.

Buzon et al., 2007
M. R. Buzon/A. Simonetti/R. A. Creaser, Migration in the Nile Valley during the New Kingdom period: A preliminary strontium isotope study. Journal of Archaeological Science 34, 2007, 1391–1401.

Cahill Wilson et al., 2012
J. Cahill Wilson/H. Usborne/C. Taylor/P. Ditchfield/A. W. G. Pike, Strontium and oxygen isotope analysis on Iron Age and Early Historic burials around the Great Mound at Knowth, Co. Meath, Appendix 5. In: G. Eogan (Ed.), Excavations at Knowth 5: The archaeology of Knowth in the first and second millennia AD (Dublin 2012) 775–788.

Champion, 1990
Th. Champion, Migration revived. Journal of Danish Anthropology 9, 1990, 214–218.

Chapman/Dolukhanov, 1992
J. Chapman/P. M. Dolukhanov, The baby and the bathwater. Pulling the plug on migrations. American Anthropologist 94, 1992, 169–174.

Chapman/Hamerow, 1997
J. Chapman/H. Hamerow (Eds.), Migrations and invasions in archaeological explanation (Oxford 1997).

Chenery et al., 2010
C. Chenery/G. Müldner/J. Evans/H. Eckardt/M. Lewis, Strontium and stable isotope evidence for diet and mobility in Roman Gloucester, UK. Journal of Archaeological Science 37, 2010, 150–163.

Chenery et al., 2011
C. Chenery/H. Eckardt/G. Müldner, Cosmopolitan Catterick? Isotopic evidence for population mobility on Rome's northern frontier. Journal of Archaeological Science 38, 2011, 1525–1536.

Chenery et al., 2012
C. A. Chenery/V. Pashley/A. L. Lamb/H. J. Sloane/J. A. Evans, The oxygen isotope relationship between the phosphate and structural carbonate fractions of human bioapatite. Rapid Communications in Mass Spectrometry 2012, 26, 309–319.

Černych, 2003
L. A. Černych, Spektralanalyse und Metallverarbeitung in den früh- und mittelbronzezeitlichen Kulturen der ukrainischen Steppe als Forschungsproblem. Eurasia Antiqua 9, 2003, 27–62.

Chernykh, 1992
E. N. Chernykh, Ancient metallurgy in the USSR. The Early Metal Age (Cambridge 1992).

Černych, 1991
E. N. Černych, Frühestes Kupfer in den Steppen- und Waldsteppenkulturen. In: J. Lichardus (Ed.), Die Kupferzeit als historische Epoche. Saarbrücker Beiträge zur Altertumskunde 55 (Bonn 1991) 581–592.

Chernykh, 2008
E. N. Chernykh, Formation of the Eurasian "steppe belt" of stockbreeding cultures: Viewed through the prism of archaeometallurgy and radiocarbon dating. Archaeology, Ethnology and Anthropology of Eurasia 35/3, 2008, 36–53.

Chernykh, 2009
E. N. Chernykh, Formation of the Eurasian steppe belt cultures. Viewed through the lens of archaeometallurgy and radiocarbon dating. In: B. K. Hanks/K. M. Linduff (Eds.), Social complexity in Prehistoric Eurasia. Monuments, metals and mobility (Cambridge/New York etc. 2009) 115–145.

Černych et al., 1991
E. N. Černych/L. I. Avilova/T. B. Barčeva/L. B. Orlovskaja/T. O. Tenejšvili, The Circum-pontic metallurgical province as a system. In: J. Lichardus (Ed.), Die Kupferzeit als historische Epoche. Saarbrücker Beiträge zur Altertumskunde 55 (Bonn 1991) 593–622.

Černych et al., 1998
E. N. Černych/E. E. Antipina/E. J. Lebedeva, Produktionsformen der Urgesellschaft in den Steppen Osteuropas (Ackerbau, Viehzucht, Erzgewinnung und Verhüttung). In: B. Hänsel/J. Machnik (Eds.), Das Karpatenbecken und die osteuropäische Steppe. Nomadenbewegung und Kulturaustausch in den vorchristlichen Metallzeiten (4000–500 v. Chr.). Südosteuropa-Schriften 20, Prähistorische Archäologie in Südosteuropa 12 (München/Rahden (Westf.) 1998) 233–252.

Chiaradia, 2003
M. Chiaradia/A. Gallay/W. Todt, Different contamination styles of prehistoric human teeth at a Swiss necropolis (Sion, Valais) inferred from lead and strontium isotopes. Applied Geochemistry 18, 2003, 353–370.

Childe, 1925
V. G. Childe, The dawn of European civilization (London 1925).

Childe, 1929
V. G. Childe, The Danube in prehistory (Oxford 1929).

Childe, 1930
V. G. Childe, The Bronze Age (London 1930).

Childe, 1958
V. G. Childe, The prehistory of European society (London 1958).

Chisholm et al., 1982
B. S. Chisholm/D. E. Nelson/H. P. Schwarcz, Stable-carbon isotope ratios as a measure of marine versus terrestrial protein in ancient diets. Science 216, 1982, 1131–1132.

Ciugudean, 1995
H. Ciududean, Manifestări etno-culturale aparţinând bronzului timpuriu transilvănean. In: M. Petrescu-Dimboviţa et al. (Eds.), Comori ale epocii bronzului din România – Treasures of the Bronze Age in Romania (Bucureşti 1995) 137–147.

Ciugudean, 1998
H. Ciugudean, The Early Bronze Age in Western Transylvania. In: H. Ciugudean/F. Gogaltan (Eds.), The Early and Middle Bronze Age in the Carpathian Basin. Proceedings of the international symposium in Alba Iulia 1997. Biblioteca Musei Apulensis VIII, 1998, 67–84.

Ciugudean, 2011
H. Ciugudean, Mounds and Mountains: Burial Rituals in Early Bronze Age Transylvania. In: S. Berecki/R. E. Németh/B. Rezi (Eds), Bronze Age rites and rituals in the Carpathian Basin. Proceedings of the international colloquium from Târgu Mureş, 8–10 October 2010 (Târgu Mureş 2011) 21–57.

Clark, 1966
J. G. D. Clark, The invasion hypothesis in British prehistory. Antiquity 40, 1966, 172–189.

Clark, 1994
G. A. Clark, Migration as an explanatory concept in Palaeolithic archaeology. Journal of Archaeological Method and Theory 1/4, 1994, 305–343.

Coblenz/Fritzsche, 1961
W. Coblenz/K. Fritzsche, Dreifache Rinderbestattung mit Kugelamphoren aus Zauschwitz, Kr. Borna. Ausgrabungen und Funde 6, 2, 1961, 62–69.

Coblenz/Fritzsche, 1962
W. Coblenz/K. Fritsche, Doppelbestattung der Kugelamphorenkultur neben der rituellen Rinderbeisetzung von Zauschwitz. Ausgrabungen und Funde 7, 2, 1962, 77–82.

Cook et al., 2001
G. T. Cook/C. Bonsall/R. E. M. Hedges/K. McSweeney/V. Boroneanţ/P. B. Pettitt, A freshwater diet-derived ^{14}C reservoir effect at the Stone Age sites in the Iron Gates gorge. In: I. Carmi/E. Boaretto (Eds.), Proceedings of the 17th international radiocarbon conference, Judean Hills, Israel, 18–23 June 2000. Radiocarbon 43 (2A), 2001, 453–460.

Coplen et al., 1983
T. B. Coplen/C. Kendall/J. Hopple, Comparison of stable isotope reference samples. Nature 302, 1983, 236–238.

Coplen, 1988
T. B. Coplen, Normalization of oxygen and hydrogen isotope data. Chemical Geology: Isotope Geoscience Section 72, 1988, 293–297.

Craig, 1957
H. Craig, Isotopic standards for carbon and oxygen correction factors for mass spectrometric analysis for carbon dioxide. Geochimica et Cosmochimica Acta 12, 1957, 133–149.

Crawford/Leonard, 2002
M. H. Crawford/W. R. Leonard, The biological diversity of herding populations: an introduction. In: W. R. Leonard/M. H. Crawford (Eds.), Human biology of pastoral populations (Cambridge 2002) 1–9.

Cribb, 1991
R. Cribb, Nomads in archaeology. New studies in archaeology (Cambridge et al. 1991).

Czebreszuk/Szmyt, 2011
J. Czebreszuk/M. Szmyt, Identities, Differentiation and interactions on the Central European plain in the 3rd millennium BC. In: S. Hansen/J. Müller (Eds.), Sozialarchäologische Perspektiven: Gesellschaftlicher Wandel 5000–1500 v. Chr. zwischen Atlantik und Kaukasus. Internationale Tagung 15.–18. Oktober 2007 in Kiel. Archäologie in Eurasien 24 (Darmstadt 2011) 269–291.

D'Angela/Longinelli, 1990
D. D'Angela/A. Longinelli, Oxygen isotopes in living mammal's bone phosphate: further results. Chemical Geology 86, 1990, 75–82.

D'Angela/Longinelli, 1993
D. D'Angela/A. Longinelli, Oxygen isotopic composition of fossil mammal bones of Holocene age: Palaeoclimatological considerations. Chemical Geology 103, 1993, 171–179.

Dani/Nepper, 2006
J. Dani/I. M. Nepper, Sárrétudvari-Őrhalom. Tumulus grave from the beginning of the EBA in Eastern Hungary. Communicationes Archaeologicae Hungariae 2006.

Dansgaard, 1964
W. Dansgaard, Stable isotopes in precipitation. Tellus 16, 1964, 436–468.

Daux et al., 2008
V. Daux/Ch. Lécuyer/M.-A. Héran/R. Amiot/L. Simon/F. Fourel/F. Martineau/N. Lynnerup/H. Reychler/G. Escarguel, Oxygen isotope fractionation between human phosphate and water revisited. Journal of Human Evolution 55, 2008, 1138–1147.

Delgado Huertas et al., 1995
A. Delgado Huertas/P. Iacumin/B. Stenni/B. Sanchez Chillón/A. Longinelli, Oxygen isotope variations of phosphate in mammalian bone and tooth enamel. Geochimica et Cosmochimica Acta 59 (20), 1995, 4299–4305.

DeNiro, 1985
M. J. DeNiro, Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. Nature 317, 1985, 806–809.

DeNiro/Epstein, 1978
M. J. DeNiro/S. Epstein, Influence of diet on the distribution of carbon isotopes in animals. Geochimica et Cosmochimica Acta 42, 1978, 495–506.

DeNiro/Epstein, 1981
M. J. DeNiro/S. Epstein, Influence of diet on the distribution of nitrogen isotopes in animals. Geochimica et Cosmochimica Acta 45, 1981, 341–351.

DeNiro/Schoeninger, 1983
M. J. DeNiro/M. J. Schoeninger, Stable carbon and nitrogen isotope ratios of bone collagen: variations within individuals, between sexes, and within populations raised on monotonous diets. Journal of Archaeological Science 10, 1983, 199–203.

Demkin et al., 2000
V. A. Demkin/T. S. Demkina/L. S. Pesočina, Palaeoecology of the Eastern Europe during Scytho-Sarmatian period. In: V. I. Guljaev/V. S. Ol'chovskij (Eds.), Skify i Sarmaty v VII-III vv. do n.e.: Paleoecologija, anthropologija i archeologija (Moscow 2000) 87–90.

Dergačev, 1991
V. A. Dergačev, Bestattungskomplexe der späten Tripolje-Kultur (Mainz 1991).

Dergachev, 2002
V. A. Dergachev, The Studies in Defense of the Migration Concept. In: K. Boyle/C. Renfrew/M. Levine (Eds.), Ancient interactions: East and west in Eurasia (Cambridge 2002) 93–112.

Dergačev/Bočkarev, 2006
V. Dergačev, V. Bočkarev, Secerile de Metal din Epoca Bronzului tarziu din Europa de Est (Iaşi 2006).

Döhle, 1988
H.-J. Döhle, Die neolithischen Rinderskelette von Zauschwitz, Kr. Borna, aus archäologischer Sicht. Beiträge zur Archäozoologie 7. Zu Ehren von Hans-Joachim Barthel zum 65. Geburtstag und Manfred Teichert zum 60. Geburtstag (Weimar 1988) 28–36.

Döhle/Stahlhofen, 1985
H.-J. Döhle /H. Stahlhofen, Die neolithischen Rindergräber auf dem "Löwenberg" bei Derenburg, Kr. Wernigerode. Jahresschrift für mitteldeutsche Vorgeschichte 68, 1985, 157–177.

Döhle/Schlenker, 1998
H.-J. Döhle /B. Schlenker, Ein Tiergrab der Kugelamphorenkultur von Oschersleben, Ldkr. Bördekreis. Jahresschrift für mitteldeutsche Vorgeschichte 80, 1998, 13–42.

Döhle/Pape, 2006
H.-J. Döhle/J. Pape, Ein Grabmal der Kugelamphorenkultur auf dem Jätchenberg. In: H. Meller (Ed.) Archäologie XXL. Archäologie an der B 6n im Landkreis Quedlinburg. Archäologie in Sachsen-Anhalt. Sonderband 4 (Halle (Saale) 2006) 83–88.

Dolukhanov, 2009
P. M. Dolukhanov, Geography of the East European Plain. In: P. M. Dolukhanov/G. R. Sarson/A. M. Shukurov (Eds.), The East European Plain on the eve of agriculture. BAR International Series 1964 (Oxford 2009) 9–21.

Dolukhanov et al., 2009
P. M. Dolukhanov/A. M. Shukurov/K. Davison/G. Sarson/N. P. Gerasimenko/G. A. Pashkevich/A. A. Vybornov/N. N. Kovalyukh/V. V. Skripkin/G. I. Zaitseva/T. V. Sapelko, The spread of the Neolothic in the south east European plain: Radiocarbon chronology, subsistence, and environment. Radiocarbon 51/2, 2009, 783–793.

Drucker/Bocherens, 2004
D. Drucker/H. Bocherens, Carbon and nitrogen stable isotopes as tracers of change in diet breadth during Middle and Upper Palaeolithic in Europe. International Journal of Osteoarchaeology 14, 2004, 162–177.

Drucker et al., 2008
D. G. Drucker/A. Bridault/K. A. Hobson/E. Szuma/H. Bocherens, Can carbon-13 in large herbivores reflect the canopy effect in temperate and boreal ecosystems? Evidence from modern and ancient ungulates. Palaeogeography, Palaeoclimatology, Palaeoecology 266, 2008, 69–82.

Dürrwächter et al., 2003
C. Dürrwächter/O. E. Craig/G. Taylor/M. J. Collins/J. Burger/K. W. Alt, Rekonstruktion der Ernährungsweise in den mittel- und frühneolithischen Bevölkerungen von Trebur/Hessen und Herxheim/Pfalz anhand der Analyse stabiler Isotope. Bulletin der Schweizerischen Gesellschaft für Anthropologie 9 (2), 2003, 1–16.

Dürrwächter et al., 2006
C. Dürrwächter/O. E. Craig/G. Taylor/M. J. Collins/J. Burger/K. W. Alt, Beyond the grave: variability in Neolithic diets in Southern Germany? Journal of Archaeological Science 33, 2006, 39–48.

Dufour et al., 2007
E. Dufour/C. Holmden/W. van der Neer/A. Zazzo/W. P. Patterson/P. Degryse/E. Keppens, Oxygen and strontium isotopes as provenance indicators of fish at archaeological sites: the case study of Sagalassos, SW Turkey. Journal of Archaeological Science 34, 2007, 1226–1239.

Dupras et al., 2001
T. L. Dupras/H. P. Schwarcz, Strangers in a strange land: Stable isotope evidence for human migration in the Dakhleh Oasis, Egypt. Journal of Archaeological Science 28 (11), 2001, 1199–1208.

Dvornichenko, 1995
V. V. Dvornichenko, Sauromatians and Sarmatians of the Eurasian Steppes: The transition period from the Bronze Age. In: J. Davis-Kimball/V. A. Bashilov/L. T. Yablonsky (Eds.), Nomads of the Eurasian steppes in the Early Iron Age (Berkeley, NJ 1995)101–104.

Eckardt et al., 2009
H. Eckardt/C. Chenery/P. Booth/J. A. Evans/A. Lamb/G. Müldner, Oxygen and strontium isotope evidence for mobility in Roman Winchester. Journal of Archaeological Science 36, 2009, 2816–2825.

Ecsedy, 1979
I. Ecsedy, The people of the Pit-Grave kurgans in Eastern Hungary. Fontes Archaeologici Hungariae (Budapest 1979).

Ericson, 1981
J. E. Ericson, Residence patterns by isotopic characterization. Paper presented at the Society for American Archaeology (San Diego, CA 1981).

Ericson, 1985
J. E. Ericson, Strontium isotope characterization in the study of prehistoric human ecology. Journal of Human Evolution 14, 1985, 503–514.

Evans/Tatham, 2004
J. A. Evans/S. Tatham, Defining 'local signature' in terms of Sr isotope composition using a tenth–twelfth century Anglo-Saxon population living on a Jurassic clay-carbonate terrain, Rutland UK. Geological Society Special Publication 232, 2004, 237–248.

Evans et al., 2006
J. Evans/N. Stoodley/C. Chenery, A strontium and oxygen isotope assessment of a possible fourth century immigrant population in a Hampshire cemetery, southern England. Journal of Archaeological Science 33, 2006, 265–272.

Evans et al., 2007
J. A. Evans/S. Tatham/S. R. Chenery/C. A. Chenery, Anglo-Saxon animal husbandry techniques revealed through isotope and chemical variations in cattle teeth. Applied Geochemistry 22, 2007, 1994–2005.

Evans et al., 2010
J. A. Evans/J. Montgomery/G. Wildman/N. Boulton, Spatial variations in biosphere $^{87}Sr/^{86}Sr$ in Britain. Journal of the Geological Society 167, 2010, 1–4.

Ezzo et al., 1997
J. A. Ezzo/C. M. Johnson/T. D. Price, Analytical perspectives on prehistoric migration: A case study from East-Central Arizona. Journal of Archaeological Science 24, 1997, 447–466.

Ezzo/Price, 2002
J. A. Ezzo/T. D. Price, Migration, regional reorganization, and spatial group composition at Grasshopper Pueblo, Arizona. Journal of Archaeological Science 29, 2002, 499–520.

Faure, 1977
G. Faure, Principles of isotope geology (New York/Chichester/Brisbane/Toronto/Singapore 1977).

Faure, 1986
G. Faure, Principles of isotope geology. 2nd edition (New York/Chichester/Brisbane/Toronto/Singapore 1977).

Faure/Mensing, 2005
G. Faure/T. M. Mensing, Isotopes: Principles and applications. 3rd edition (Hoboken, NJ 2005).

Ferret, 2009
C. Ferret, Une civilisation du cheval (Paris 2009).

Fink et al., 1977
J. Fink/G. Haase/R. Ruske, Bemerkungen zur Lößkarte von Europa 1: 2,5 Mio. In: Petermanns Geographische Mitteilungen 77 (2), 1977, 81–94.

Fischer et al., 2007
A. Fischer/J. Olsen/M. Richards/J. Heinemeier/A. E. Sveinbjörnsdóttir/P. Bennike, Coast – inland mobility and diet in the Danish Mesolithic and Neolithic: Evidence from stable isotope values of humans and dogs. Journal of Archaeological Science 34, 2007, 2125–2150.

Förstel/Hützen, 1983
H. Förstel/H. Hützen, Oxygen isotope ratios in German groundwater. Nature 304, 1983, 614–616.

Frachetti, 2008a
M. D. Frachetti, Pastoralist landscapes and social interaction in Bronze Age Eurasia (Berkeley, NJ/Los Angeles, CA/London 2008).

Frachetti, 2008b
M. D. Frachetti, Variability and dynamic landscapes o mobile pastoralism in ethnography and prehistory. In: H. Barnard/W. Wendrich (Eds.), The archaeology of mobility. Old World and New World nomadism. Cotsen Advanced Seminars 4 (Los Angeles, CA 2008) 366–396.

Frachetti, 2009
M. D. Frachetti, Differentiated landscapes in non-uniform complexity among Bronze Age societies of the Eurasian steppe. In: B. K. Hanks/K. M. Linduff (Eds.), Social complexity in prehistoric Eurasia. Monuments, metals, and mobility (Cambridge/New York etc. 2009) 19–46.

Frachetti, 2011
M. D. Frachetti, Migration concepts in Central Eurasian archaeology. Annual Review of Anthropology 40, 2011, 195–212.

Frachetti/Benecke, 2009
M. Frachetti/N. Benecke, From sheep to (some) horses: 4500 years of herd structure at the pastoralist settle-

ment of Begash (south-east Kazakhstan). Antiquity 83/322, 2009, 1023–1037.

Frank/Nalbandian, 1989
R. M. Frank/J. Nalbandian, Structure and ultrastructure of dentine. In: B. K. B. Berkovitz/A. Boyde/R. M. Frank/H. J. Höhling/B. J. Moxham/J. Nalbandian/C. H. Tonge (Eds.), Teeth (Berlin et al. 1989) 73–171.

Franz, 1984
P. Franz, Soziologie der räumlichen Mobilität. Eine Einführung (Frankfurt (Main) 1984).

Fricke/O'Neil, 1996
H. C. Fricke/J. O'Neil, Inter- and intra-tooth variation in the oxygen isotope composition of mammalian tooth enamel phosphate: implications for palaeoclimatological and palaeobiological research. Palaeogeography, Palaeoclimatology, Palaeoecology 126, 1996, 91–99.

Fricke/O'Neil, 1999
H. C. Fricke/J. R. O'Neil, The correlation between $^{18}O/^{16}O$ ratios of meteoric water and surface temperature: its use in investigating terrestrial climate change over geologic time. Earth Planetary Science Letters 170 (3), 1999, 181–196.

Frobenius, 1898
L. Frobenius, Der Ursprung der afrikanischen Kulturen (Berlin 1898).

Fuller et al., 2006
B. T. Fuller/T. I. Molleson/D. A. Harris/L. T. Gilmour/R. E. M. Hedges, Isotopic evidence for breastfeeding and possible adult dietary differences from late/Subroman Britain. American Journal of Physical Anthropology 129, 2006, 45–54.

Gat, 1996
J. R. Gat, Oxygen and hydrogen isotopes in the hydrologic cycle. Annual Review of Earth and Planetary Sciences 24 (1), 1996, 225–262.

Gej, 2004
A. N. Gej, Die Wagen der Novotitarovskaja-Kultur. In: M. Fansa/St. Burmeister (Eds.), Rad und Wagen. Der Ursprung einer Innovation. Wagen im Vorderen Orient und Europa (Mainz 2004) 177–190.

Gerasimenko, 1997
N. P. Gerasimenko, Environmental and climatic changes between 3 and 5 ka BP in southeastern Ukraine. In: H. N. Dalfes/G. Kukla/H. Weiss (Eds.), Third millennium BC climate change and Old World collapse. NATO ASI Ser. I: Global Environmental Change 49 (Berlin 1997) 371–399.

Gerling et al., 2012a
C. Gerling/V. Heyd/A. Pike/E. Bánffy/J. Dani/K. Köhler/G. Kulcsár/E. Kaiser/W. Schier, Identifying kurgan graves in Eastern Hungary – A burial mound in the light of strontium and oxygen isotope analysis. In: E. Kaiser/J. Burger/W. Schier (Eds.), Population dynamics in prehistory and early history. New approaches using stable isotopes and genetics. Topoi. Berlin Studies of the Ancient World 5 (Berlin 2012) 165–176.

Gerling et al., 2012b
C. Gerling/E. Bánffy/J. Dani/K. Köhler/G. Kulcsár/A. Pike/V. Szeverényi/V. Heyd, Immigration and transhumance in the Early Bronze Age Carpathian Basin: The occupants of a kurgan. Antiquity 86, 2012, 1097–1111.

Giblin, 2004
J. Giblin, Strontium isotope and trace element analysis of Copper Age human skeletal material from the Great Hungarian Plain. Thesis Florida State University 2004. Available online: http://dscholarship.lib.fsu.edu/undergrad/43 (accessed 13. 05. 2011).

Giblin, 2009
J. I. Giblin, Strontium isotope analysis of Neolithic and Copper Age populations on the Great Hungarian Plain. Journal of Archaeological Science 36, 2009, 491–497.

Gimbutas, 1956
M. Gimbutas, Prehistory of Eastern Europe. Band 1: Mesolithic, Neolithic and Copper Age cultures in Russia and the Baltic Area. Bull. Am. Sch. Preh. Res. 20 (Cambridge, Mass. 1956).

Gimbutas, 1977
M. Gimbutas, The first wave of Eurasian steppe pastoralists into Copper Age Europe. Journal of Indo-European Studies 5, 1977, 277–337.

Gimbutas, 1979
M. Gimbutas, The three waves of the steppe people into East Central Europe. Archives Suisses d'Anthropologie Generale 43, 1979, 113–137.

Gimbutas, 1994
M. Gimbutas, Das Ende Alteuropas. Der Einfall von Steppennomaden aus Südrußland und die Indogermanisierung Mitteleuropas (Innsbruck 1994).

Gimbutas, 1997
M. Gimbutas, The Three Waves of the Kurgan People into Old Europe, 4500–2500 B.C. In: M. R. Dexter/K. Jones-Bley (Eds.), M. Gimbutas, The Kurgan Culture and the Indo-Europeanization of Europe. Selected articles from 1952 to 1993. Journal of Indo-European Studies Monographs 18 (Washington, D.C. 1997) 240–266. [Reprint of Archives Suisses d'anthropologie générale 43 (2), 1979, 113–137].

Golden, 2008
P. Golden, The peoples of the south Russian steppes. In: D. Sinor (Ed.), The Cambridge History of Early Inner Asia (Cambridge 1990) 256–284.

Govedarica, 2010
B. Govedarica, Spuren von Fernbeziehungen in Norddeutschland während des 5. Jahrtausends v. Chr. Das Altertum 55 (1), 2010, 1–12.

Govedarica/Manzura, 2011
B. Govedarica/I. Manzura, Grundzüge einer Kulturgeschichte des nordwestlichen Schwarzmeergebietes im 5. und 4. Jahrtausend v. Chr. In: E. Sava/B. Govedarica/B. Hänsel (Eds.), Der Schwarzmeerraum vom Äneolithikum bis in die Früheisenzeit (5000–500 v. Chr.), Globale Entwicklung versus Lokalgeschehen. PAS 27 (Rhaden (Westf.) 2011) 41–62.

Govedarica et al., 2006
B. Govedarica/E. Kaiser/J. J. Rassamakin/V. A. Samar, Der Grabhügel 'Tarasova Mogila' bei der Stadt Orechov. Eurasia Antiqua 12, 2006, 63–112.

Govedarica/Kaiser, 1996
B. Govedarica/E. Kaiser, Die äneolitischen abstrakten und zoomorphen Steinzepter Südost- und Osteuropas. Eurasia Antiqua 2, 1996, 59–103.

Graebner, 1911
F. Graebner, Methode der Ethnologie (Heidelberg 1911).

Grupe et al., 1997
G. Grupe/T. D. Price/P. Schröter/F. Söllner/C. M. Johnson/B. L. Beard, Mobility of Bell Beaker people revealed by strontium isotope ratios of tooth and bone: a study of southern Bavarian skeletal remains. Applied Geochemistry 12, 1997, 517–525.

Grupe et al., 2003
G. Grupe/H. Manhart/Ž. Mikić/J. Peters, Vertebrate food webs and subsistence strategies of Meso- and Neolithic populations of central Europe. In: G. Grupe/J. Peters (Eds.), Documenta Archaeobiologiae 1 (Rahden (Westf.) 2003) 193–213.

Grupe/Peters, 2009
G. Grupe/J. Peters, Molecular biological methods applied to Neolithic bioarchaeological remains: Research potential, problems, and pitfalls. In: L. Larsson/F. Lüth/T. Terberger (Eds.), Innovation and continuity – Non-Megalithic mortuary practices in the Baltic. New methods and research into the development of Stone Age society. International Workshop at Schwerin on 24–26 March 2006. Bericht der Römisch-Germanischen Kommission 88 (Mainz 2009) 275–306.

Haak et al., 2008
W. Haak/G. Brandt/H. N. de Jong/Ch. Meyer/R. Ganslmeier/V. Heyd/Ch. Hawkesworth/A. W. G. Pike/H. Meller/K. W. Alt, Ancient DNA, strontium isotopes, and osteological analyses shed light on social and kinship organization of the Later Stone Age. Proceedings of the National Academy of Sciences of the United States of America 105, 2008, 18226–18231.

Haak et al., 2010
W. Haak/G. Brandt/Ch. Meyer/H. N. de Jong/R. Ganslmeier/A. W. G. Pike/H. Meller/K. Alt, Die schnurkeramischen Familiengräber von Eulau – ein außergewöhnlicher Fund und seine interdisziplinäre Bewertung. In: H. Meller/K. W. Alt (Eds.), Anthropologie, Isotopie und DNA – biografische Annäherung an namenlose vorgeschichtliche Skelette? Tagungen des Landesmuseums für Vorgeschichte Halle 3 (Halle (Saale) 2010) 53–62.

Hänsel, 1998
B. Hänsel, Die Steppe im Spannungsfeld zwischen nomadischen und sesshaften Lebensformen – Eine Einführung in das Thema. In: B. Hänsel/J. Machnik (Eds.), Das Karpatenbecken und die osteuropäische Steppe. Nomadenbewegung und Kulturaustausch in den vorchristlichen Metallzeiten (4000–500 v. Chr.). Südosteuropa-Schriften 20, Prähistorische Archäologie in Südosteuropa 12 (München/Rahden (Westf.) 1998) 9–18.

Hänsel/Machnik, 1998
B. Hänsel/J. Machnik (Eds.), Das Karpatenbecken und die osteuropäische Steppe. Nomadenbewegung und Kulturaustausch in den vorchristlichen Metallzeiten (4000–500 v. Chr.). Südosteuropa-Schriften 20, Prähistorische Archäologie in Südosteuropa 12 (München/Rahden (Westf.) 1998).

Härke, 1997
H. Härke, Wanderungsthematik, Archäologen und politisches Umfeld. Archäologische Informationen 20/1, 1997, 61–71.

Häusler, 1974
A. Häusler, Die Gräber der älteren Ockergrabkultur zwischen Ural und Dnepr. Wissenschaftliche Beiträge der Martin-Luther-Universität Halle-Wittenberg 1974/2 (Halle 1974).

Häusler, 1976
A. Häusler, Die Gräber der älteren Ockergrabkultur zwischen Dnepr und Karpaten (Berlin 1976).

Häusler, 1998
A. Häusler, Struktur und Evolution der Bestattungssitten zwischen Wolga und Karpatenbecken vom Äneolithikum bis zur frühen Bronzezeit. Ein diachroner Vergleich. In: B. Hänsel/J. Machnik (Eds.), Das Karpatenbecken und die osteuropäische Steppe. Nomaden-

bewegung und Kulturaustausch in den vorchristlichen Metallzeiten (4000–500 v. Chr.). Südosteuropa-Schriften 20, Prähistorische Archäologie in Südosteuropa 12 (München/Rahden (Westf.) 1998). 135–161.

Hampel, 2005
G. Hampel, Fleischrinderzucht und Mutterkuhhaltung (Stuttgart 2005).

Hanks, 2010
B. Hanks, Archaeology of the Eurasian Steppes and Mongolia. Annual Review of Anthropology 39, 2010, 469–486.

Hanks/Linduff, 2009
B. K. Hanks/K. M. Linduff (Eds.), Social complexity in Prehistoric Eurasia. Monuments, metals, and mobility (Cambridge/New York etc. 2009).

Hansen, 2011
S. Hansen, Technische und soziale Innovationen in der zweiten Hälfte des 4. Jahrtausends v. Chr. In: S. Hansen/J. Müller (Eds.), Sozialarchäologische Perspektiven: Gesellschaftlicher Wandel 5000–1500 v. Chr. zwischen Atlantik und Kaukasus (Darmstadt 2011) 153–192.

Harrison/Heyd, 2007
R. Harrison/V. Heyd, The transformation of Europe in the third millennium BC: The example of 'Le Petit-Chasseur I + III' (Sion, Valais, Switzerland). Prähistorische Zeitschr. 82, 2007, 129–214.

Haverkort et al., 2008
C. Haverkort/A. W. Weber/M. A. Katzenberg/O. I. Goriunova/A. Simonetti/R. A. Creaser, Hunter-gatherer mobility strategies and resource use based on strontium isotope (87Sr/86Sr) analysis: A case study from Middle Holocene Lake Baikal, Siberia. Journal of Archaeological Science 35, 2008, 1265–1280.

Heaton et al., 1986
T. H. E. Heaton/J. C. Vogel/G. von la Chevallerie/G. Collett, Climatic influence on the isotopic composition of bone collagen. Nature 322, 1986, 822–823.

Heaton, 1999
T. H. E. Heaton, Spatial, species, and temporal variations in the $^{13}C/^{12}C$ Ratios of C_3 plants: Implications for palaeodiet studies. Journal of Archaeological Science 26, 1999, 637–649.

Hedges, 2003
R. E. M. Hedges, On bone collagen – apatite-carbonate isotopic relationships, International Journal of Osteoarchaeology, 13, 2003, 66–79.

Hedges/Reynard, 2007
R. E. M. Hedges/L. M. Reynard, Nitrogen isotopes and the trophic level of humans in archaeology. Journal of Archaeological Science 34, 2007, 1240–1251.

Hedges et al., 2004
R. E. M. Hedges/R. E. Stevens/M. P. Richards, Bone as a stable isotope archive for local climatic information. Quaternary Science Reviews 23, 2004, 959–965.

Hedges et al., 2007
R. E. M. Hedges/J. G. Clement/D. L. Thomas/T. C. O'Connell, Collagen turnover in the adult femoral midshaft: Modelled from anthropogenic radiocarbon tracer measurements. American Journal of Physical Anthropology 133, 2007, 808–816.

Henton et al., 2010
E. Henton/W. Meier-Augenstein/H. F. Kemp, The use of oxygen isotopes in sheep molars to investigate past herding practices at the Neolithic settlement of Çatalhöyük, Central Anatolia. Archaeometry 52/3, 2010, 429–449.

Heyd et al., 2002/2003
V. Heyd/B. Winterholler/K. Böhm/E. Pernicka, Mobilität, Strontiumisotopie und Subsistenz in der süddeutschen Glockenbecherkultur. Berichte der Bayerischen Bodendenkmalpflege 43/44, 2002/2003, 109–135.

Heyd, 2011
V. Heyd, Yamnaya Groups and Tumuli west of the Black Sea. In: E. Borgna/S. Müller-Celka (Eds.), Ancestral landscapes: Burial mounds in the Copper and Bronze Ages (Central and Eastern Europe – Balkans – Adriatic – Aegean, 4th–2nd millennium BC). International conference, Udine/Italy, May 15th–18th 2008. Travaux de la Maison de l'Orient et de la Méditerranée 58 (Lyon 2011) 529–549.

Heyd, 2012
V. Heyd, Growth and expansion: Social, economic and ideological structures in the European Chalcolithic. In: M. J. Allen/J. Gardiner/A. Sheridan (Eds.), Is there a British Chalcolithic? People, place and polity in the later 3rd millennium. Proceedings of the British Chalcolithic conference, April 2008 in Bournemouth. Prehistoric Society Research Paper 4 (London/Oxford 2012) 98–114.

Heyd, in press
V. Heyd, Das Zeitalter der Ideologien: Interaktion, Expansion & Wettbewerb im prähistorischen Europa des 4. und 3. Jahrtausends v. Chr. In: H. Hettrich (Hrsg,), Die Ausbreitung des Indogermanischen: Thesen aus Sprachwissenschaft, Archäologie und Genetik. Vorträge der Arbeitstagung der Indogermanischen Gesellschaft (Société des Études Indo-Européennes/Society for

Indo-European Studies), Julius-Maximilians-Universität Würzburg, 24. – 6. September 2009 (Wiesbaden) (in press).

Heyd/Walker, in press
V. Heyd/K. Walker, The first metalwork and expressions of social power. In: C. Fowler/J. Harding/D. Hofmann (Eds.), The Oxford handbook of Neolithic Europe (Oxford) (in press).

Higgins/MacFadden, 2004
P. Higgins/B. J. MacFadden, "Amount effect" recorded in oxygen isotopes of Late Glacial horse (Equus) and bison (Bison) teeth from the Sonoran and Chihuahuan deserts, southwestern United States. Palaeogeography, Palaeoclimatology, Palaeoecology 206, 2004, 337–353.

Higham et al., 2010
T. Higham/R. Warren/A. Belinskij/H. Härke/R. Wood, Radiocarbon dating, stable isotope analysis, and diet-derived offsets in 14C ages from the Klein-Yar site, Russian North Caucasus. Radiocarbon 52, 2010, 653–670.

Hillson, 1996
S. Hillson, Dental anthropology (Cambridge 1996).

Hillson/Antoine, 2003
S. Hillson/D. Antoine, Ancient bones and teeth on the microstructural level. In: G. Grupe/J. Peters (Eds.), Decyphering ancient bones. The research potential of bioarchaeological collections. Documenta Archaeobiologiae 1 (Rahden (Westf.) 2003) 141–157.

Hoefs, 1987
J. Hoefs, Stable Isotope Geochemistry (Berlin/Heidelberg/New York 1987).

Hodell et al., 2004
D. A. Hodell/R. L. Quinn/M. Brenner/G. Kamenov, Spatial variation of strontium isotopes ($^{87}Sr/^{86}Sr$) in the Maya region: a tool for tracking ancient human migration. Journal of Archaeological Science 31, 2004, 585–601.

Hoekman-Sites/Giblin, 2012
H. A. Hoekman-Sites/J. I. Giblin, Prehistoric animal use on the Great Hungarian Plain: A synthesis of isotope and residue analyses from the Neolithic and Copper Age. Journal of Anthropological Archaeology 31/4, 2012, 515–527.

Hollund et al., 2010
H. I. Hollund/T. Higham/A. Belinskij/S. Korenevskij, Investigation of palaeodiet in the North Caucasus (South Russia) Bronze Age using stable isotope analysis and AMS dating of human and animal bones. Journal of Archaeological Science 37, 2010, 2971–2983.

Honch et al., 2006
N. V. Honch/T. F. G. Higham/J. Chapman/B. Gaydarska/R. E. M. Hedges, A palaeodietary investigation of carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$) in human and faunal bones from the Copper Age cemeteries of Varna I and Durankulak, Bulgaria. Journal of Archaeological Science 33, 2006, 1493–1504.

Hoogewerff et al., 2001
J. Hoogewerff/W. Papesch/M. Kralik/M. Berner/P. Vroon/H. Miesbauer/O. Gabler/K.-H. Künzel/J. Kleinjans, The last domicil of the Iceman from Hauslabjoch: A geochemical approach using Sr, C and O isotopes and trace element signatures. Journal of Archaeological Science 28, 2001, 983–989.

Hoppe, 2006
K. A. Hoppe, Correlation between the oxygen isotope ratio of North American bison teeth and local waters: Implication for paleoclimatic reconstructions. Earth Planetary Science Letters 244, 2006, 408–417.

Hoppe et al., 1999
K. A. Hoppe/P. L. Koch/R. W. Carlson/S. D. Webb, Tracking mammoths and mastodons. Reconstruction of migratory behaviour using strontium isotope ratios. Geology 27/5, 1999, 439–442.

Hoppe et al., 2004
K. A. Hoppe/S. M. Stover/J. R. Pascoe/R. Amundson, Tooth enamel biomineralization in extant horses: implications for isotopic microsampling. Palaeogeography, Palaeoclimatology, Palaeoecology 206, 355–365.

Hoppe et al., 2005
K. A. Hoppe/S. Stushka/R. Amundson, The implications for paleodietary and paleoclimatic reconstructions of intrapopulation variability in the oxygen and carbon isotopes of teeth from modern feral horses, Quaternary Research 64, 2005, 138–146.

Horváth, 2011
T. Horváth, Hajdúnánás-Tedej-Lyukas-halom – An interdisciplinary survey of a typical kurgan from the Great Hungarian Plain region: A case study (The revision of the kurgans from the territory of Hungary). In: Á. Pető/A. Barczi (Eds.), Kurgan Studies. An environmental and archaeological multiproxy study of burial mounds in the Eurasian steppe zone. BAR International Series 2238 (Oxford 2011) 71–131.

Hütteroth, 1959
E.-D. Hütteroth, Bergnomaden und Yaylabauern im mittleren kurdischen Taurus. Marburger Geographische Schriften 11 (Marburg 1959).

Iacumin et al., 1996
P. Iacumin/H. Bocherens/A. Mariotti/A. Longinelli, An isotopic palaeoenvironmental study of human skeletal remains from the Nile Valley. Palaeogeography, Palaeoclimatology, Palaeoecology 126, 1996, 15–30.

Iacumin et al., 2004a
P. Iacumin/V. Nikolaev/M. Ramigni/A. Longinelli, Oxygen isotope analyses of mammal bone remains from Holocene sites in European Russia: palaeoclimatic implications. Global and Planetary change 40, 2004, 169–176.

Iacumin et al., 2004b
P. Iacumin/V. Nikolaev/L. Genoni/M. Ramigni/Ya. G. Ryskov/A. Longinelli, Stable isotope analyses of mammal skeletal remains of Holocene age from European Russia: A way to trace dietary and environmental changes. Geobios 37, 2004, 37–47.

IAEA/WMO
IAEA/WMO, Global Network of Isotopes in Precipitation. The GNIP Database 2008. Available Online: http://www.iaea.org/water (accessed 15. 10. 2012).

Iliev, 2009
I. Iliev, Über das Eindringen der Grubengrabkultur in das Gebiet Thrakiens. In: V. Becker (Ed.), Zeiten – Kulturen – Systeme. Festschrift für Jan Lichardus. Schriften des Zentrums für Archäologie und Kunstgeschichte des Schwarzmeerraumes (Langenweißbach 2009) 241–246.

Ivantchik, 2007
A. Ivantchik, Zum Totenritual skythischer "Könige": Herodot und der archäologische Befund. In: W. Menghin/H. Parzinger (Eds.), Im Zeichen des goldenen Greifen. Königsgräber der Skythen (München/London/New York 2007) 238–241.

Jacobson-Tepfer, 2008
E. Jacobson-Tepfer, The emergence of cultures of mobility in the Altai mountains of Mongolia: Evidence from the intersection of rock art and palaeoenvironment. In: H. Barnard/W. Wendrich (Eds.), The archaeology of mobility. Old World and New World nomadism. Cotsen Advanced Seminars 4 (Los Angeles, CA 2008) 200–229.

Jay/Richards, 2006
M. Jay/M. P. Richards, Diet in the Iron Age cemetery population at Wetwang Slack, East Yorkshire, UK: Carbon and nitrogen stable isotope evidence. Journal of Archaeological Science 33, 2006, 653–662.

Jeunesse, 2006
Chr. Jeunesse, Les sépultures de paires de bovins dans le Neólithique final de l'est de l'Europe centrale. In: P. Pétrequin/R.-M. Arbogast/A.-M. Pétrequin/S. van Willigen/M. Bailly (Eds.), Premiers chariots, premiers araires. La diffusion de la traction animale en Europe pendant les IVe et IIIe millénaires avant notre ère. Monographie du CRA 29 (Paris 2006) 247–258.

Jim et al., 2006
S. Jim/V. Jones/S. H. Ambrose/R. P. Evershed, Quantifying dietary macronutrient sources of carbon for bone collagenbiosynthesis using natural abundance stable carbon isotope analysis. British Journal of Nutrition 95, 2006, 1055–1062.

Johannsen/Laursen, 2010
N. U. Johannsen/S. Laursen, Routes and wheeled transport in late 4th – early 3rd millennium funerary customs of the Jutland peninsula: Regional evidence and European context. Prähistorische Zeitschrift 85, 2010, 15–58.

de Jong et al., 2010
H. N. de Jong/G. L. Foster/V. Heyd/A. W. G. Pike, Further isotopic studies on the Eulau multiple graves using laser ablation ICP-MS. In: H. Meller/K. W. Alt (Eds.), Anthropologie, Isotopie und DNA – biografische Annäherung an namenlose vorgeschichtliche Skelette? Tagungen des Landesmuseums für Vorgeschichte Halle (Saale), 3. (Halle (Saale) 2010) 63–69.

de Jong et al., in prep.
H. N. de Jong/G. L. Foster/V. Heyd/C. D. Coath/C. J. Hawkesworth/A. W. G. Pike, LA-MC-ICP-MS $^{87}Sr/^{86}Sr$ analysis of sub-1000 ppm calcium apatite through oxide reduction (in preparation).

Jovanović, 1986
B. Jovanović, Comment on Anthony 1986, Current Anthropology 27 (4), 1986, 307.

Kaiser, 2003
E. Kaiser, Studien zur Katakombengrabkultur zwischen Dnepr und Prut. Archäologie in Eurasien 14 (Mainz 2003).

Kaiser, 2005
E. Kaiser, Frühbronzezeitliche Gräber von Metallhandwerkern mit Gußformen für Schaftlochäxte im osteuropäischen Steppenraum. In: B. Horejs/R. Jung/E. Kaiser/B. Teržan (Eds.), Interpretationsraum Bronzezeit. Bernhard Hänsel von seinen Schülern gewidmet. Universitätsforschungen zur Prähistorischen Archäologie 121 (Bonn 2005) 265–291.

Kaiser, 2006
E. Kaiser, Die Bestattungen der Katakombengrabkultur. In: K. P. Bunjatjan/E. Kaiser/A. V. Nikolova (Eds.), Bronzezeitliche Bestattungen aus dem unteren Dneprgebiet. Schriften des Zentrums für Archäologie

und Kulturgeschichte des Schwarzmeerraumes 8 (Langenweißbach 2006) 33–45.

Kaiser, 2007
E. Kaiser, Wagenbestattungen des 3. vorchristlichen Jahrtausends in der osteuropäischen Steppe. In: M. Blecic/M. Crsnar/B. Hänsel/A. Hellmuth/E. Kaiser/C. Metzner-Nebelsick, Scripta Praehistorica in honorem Biba Teržan. Situla 44 (Ljubljana 2007) 129–149.

Kaiser, 2010a
E. Kaiser, Migrationen in der Vorgeschichte am Beispiel der Jamnaja-Kultur im nordpontischen Steppenraum. Mitteilungen der Berliner Gesellschaft für Anthropologie 31, 2010, 191–202.

Kaiser, 2010b
E. Kaiser, Begraben, aber nicht vergessen. Katakomben – Eine neue Grabkonstruktion in den Grabhügeln. In: J. Leskovar/M-Ch. Zingerle (Eds.), Goldener Horizont. 4000 Jahre in der Ukraine (Weitra 2010) 22–29.

Kaiser, 2011
E. Kaiser, Egalitäre Hirtengesellschaft versus Nomadenkrieger? Rekonstruktion einer Sozialstruktur der Jamnaja- und Katakombengrabkulturen (3. Jt. v. Chr.). In: S. Hansen/J. Müller (Eds.), Sozialarchäologische Perspektiven: Gesellschaftlicher Wandel 5000–1500 v. Chr. zwischen Atlantik und Kaukasus (Darmstadt 2011) 193–210.

Kaiser, 2012
E. Kaiser, Der osteuropäische Steppenraum im 3. Jt. v. Chr. – Kulturhistorische Studien zu Subsistenzwirtschaft und Interaktionen mit benachbarten Räumen. Unveröffentlichte Habilitationsschrift Freie Universität Berlin (Berlin 2012).

Kalicz, 1969
N. Kalicz, Die Frühbronzezeit in Nordost-Ungarn. Abriss der Geschichte des 16.–19. Jahrhunderts v. u. Z. Archaeologia Hungarica XLV (Budapest 1969).

Kalicz, 1998
N. Kalicz, Östliche Beziehungen während der Kupferzeit in Ungarn. In: B. Hänsel/J. Machnik (Eds.), Das Karpatenbecken und die osteuropäische Steppe. Nomadenbewegung und Kulturaustausch in den vorchristlichen Metallzeiten (4000–500 v. Chr.). Südosteuropa-Schriften 20, Prähistorische Archäologie in Südosteuropa 12 (München/Rahden (Westf.) 1998) 163–177.

Karmyčeva, 1981
B. Ch. Karmyčeva, Versuch einer Typologisierung der traditionellen Formen der Viehwirtschaft Mittelasiens und Kasachstans am Ende des 19./Anfang des 20. Jh. In: R. Krusche (Ed.), Die Nomaden in Geschichte und Gegenwart. Beiträge zu einem internationalen Nomadismus-Symposium am 11. und 12. Dezember 1975 im Museum für Völkerkunde zu Leipzig 33 (Berlin 1981) 91–96.

Katzenberg, 2008
M. A. Katzenberg, Stable isotope analysis: A tool for studying past diet, demography, and life history. In: M. A. Katzenberg/S. R. Saunders (Eds.), Biological anthropology and the human skeleton (Hoboken, NJ 2008) 413–441.

Katzenberg/Weber, 1999
M. A. Katzenberg/A. Weber, Stable isotope ecology and palaeodiet in the Lake Baikal region of Siberia. Journal of Archaeological Science 26, 1999, 651–659.

Katzenberg et al., 2009
M. A. Katzenberg/O. I. Goriunova/A. Weber, Paleodiet reconstruction of Early Bronze Age Siberians from the site of Khuzhir-Nuge XIV, Lake Baikal. Journal of Archaeological Science 36, 2009, 663–674.

Kearney, 1986
M. Kearney, From the invisible hand to visible feet: Anthropological studies of migration and development. Annual Review of Anthropology 15, 1986, 331–361.

Keenleyside et al., 2011
A. Keenleyside/H. P. Schwarcz/K. Panayotova, Oxygen isotope evidence of residence and migration in a Greek colonial population on the Black Sea. Journal of Archaeological Science 38, 2011, 2658–2666.

Keyser-Tradqui et al., 2005
C. Keyser-Tradqui/P. Blandin-Frappin/H.-P. Francfort/F.-X. Ricaut/S. Lepetz/E. Crubézy/Z. Samashev/B. Ludes, Mitochondrial DNA analysis of horses recovered from a frozen tomb (Berel site, Kazakhstan, 3rd century BC). Animal Genetics, 36, 2005, 203–209.

Khain, 1994
V. E. Khain, Geology of Northern Eurasia (Ex-USSR) (Berlin/Stuttgart 1994).

Khazanov, 1984
A. M. Khazanov, Nomads and the outside world (Cambridge 1984).

Killgrove, 2010
K. Killgrove, Migration and mobility in Imperial Rome. PhD dissertation, UNC Chapel Hill 2010. Available online: http://www.piki.org/~kristina/Killgrove-2010-Migration-MobilityImperial-Rome.pdf (accessed 08. 08. 2011).

Kirsanow et al., 2008
K. Kirsanow/Ch. Marakewicz/N. Tuross, Stable oxygen (d18O) and hydrogen (dD) isotopes in ovicaprid dentinal collagen record seasonal variation. Journal of Archaeological Science 35, 2008,

Kitov et al., 1991
G. Kitov/I. Panayotov/P. Pavlov, Mogilni nekropoli v Lovetschkija kraj. Ranna bronzova doba. Nekropole Goran-Slatina (Nécropoles à tumulus dans la region de Lovetch. Ancien Age du Bronze. La nécropole de Goran-Slatina). Razkopki i Proučvanija 23 (Sofia 1991).

Kjellström et al., 2009
A. Kjellström/J. Storå/G. Possnert/A. Linderholm, Dietary patterns and social structures in medieval Sigtuna, Sweden, as reflected in stable isotope values in human skeletal remains. Journal of Archaeological Science 36, 2009, 2689–2699.

Klimenko et al., 2001
V. V. Klimenko/V. A. Klimanov/A. A. Sirin/A. M. Sleptsov, Climate changes in Western European Russia in the Late Holocene. Doklady Earth Sciences 377 (2), 2001, 190–194.

van Klinken, 1999
G. J. van Klinken, Bone collagen quality indicators for palaeodietary and radiocarbon measurements. Journal of Archaeological Science 26, 1999, 687–695.

van Klinken et al., 2000
G. J. van Klinken/M. P. Richards/R. E. M. Hedges, An overview of causes for stable isotopic variations in past European human populations: Environmental, ecophysiological, and cultural effects. In: S. H. Ambrose/M. A. Katzenberg (Eds.), Biogeochemical approaches to paleodietary analysis (New York 2000) 39–63.

Klochko/Sanzharov, 2003
V. I. Klochko/S. N. Sanzharov, Radiocarbon dating of Early and Middle Bronze Age relics of the Siversky Donets (Luhansk region). A preliminary report. Baltic-Pontic Studies 12, 2003, 209–211.

Knipper, 2004
C. Knipper, Die Strontiumisotopenanalyse: Eine naturwissenschaftliche Methode zur Erfassung von Mobilität in der Ur- und Frühgeschichte. Jahrbuch des Römisch-Germanischen Zentralmuseums Mainz 51, 2004/2, 589–685.

Knipper, 2010
C. Knipper, Die räumliche Organisation der linearbandkeramischen Tierhaltung. Beiträge von Isotopenanalysen. In: H. Meller/K. W. Alt (Eds.), Anthropologie, Isotopie und DNA – biografische Annäherung an namenlose vorgeschichtliche Skelette? Tagungen des Landesmuseums für Vorgeschichte Halle (Saale), 3. (Halle (Saale) 2010) 77–86.

Knipper, 2011
C. Knipper, Die räumliche Organisation der linearbandkeramischen Rinderhaltung: naturwissenschaftliche und archäologische Untersuchungen. BAR International Series 2305 (Oxford 2011).

Knipper/Price, 2010
C. Knipper/T. D. Price, Individuelle Mobilität in der Linearbandkeramik: Strontiumisotopenanalysen vom Gräberfeld Stuttgart-Mühlhausen "Viesenhäuser Hof". In: A. Krenn-Leeb/H.-J. Beier/E. Classen/F. Falkenstein/St. Schwenzer, Mobilität, Migration und Kommunikation in Europa während des Neolithikums und der Bronzezeit. Beiträge der Sitzungen der Arbeitsgemeinschaften Neolithikum und Bronzezeit während der Jahrestagung des West- und Südwestdeutschen Verbandes für Altertumsforschung e.V. in Xanten, 6.–8. Juni 2006. Varia neolithica V. Beiträge zur Ur- und Frühgeschichte Europas 53 (Langenweißbach 2010) 53–63.

Knipper et al., 2012
C. Knipper/A.-F. Maurer/D. Peters/Ch. Meyer/M. Brauns/S. J. G. Galer/U. von Freeden/B. Schöne/H. Meller/K. W. Alt, Mobility in Thuringia or mobile Thuringians: A strontium isotope study from early medieval Central German. In: E. Kaiser/J. Burger/W. Schier (Eds.), Population dynamics in prehistory and early history. New approaches using stable isotopes and genetics. Topoi. Berlin Studies of the Ancient World 5 (Berlin 2012) 287–310.

Knudson/Price, 2007
K. J. Knudson/T. D. Price, Utility of multiple chemical techniques in archaeological residential mobility studies: Case studies from Tiwanaku- and Chiribaya-affiliated sites in the Andes. American Journal of Physical Anthropology 132, 2007, 25–39.

Knudson et al., 2004
K. J. Knudson/T. D. Price/J. E. Buikstra/D. E. Blom. 2004, The use of strontium isotope analysis to investigate Tiwanaku migration and mortuary ritual in Bolivia and Peru. Archaeometry 46, 2004, 5–18.

Knudson et al., 2005
K. J. Knudson/ T. A. Tung/K. C. Nystom/D. T. Price/P. D. Fullagar, The origin of the Juch'uypampa Cave mummies: strontium isotope analysis of archaeological human remains from Bolivia. Journal of Archaeological Science 32, 2005, 903–913.

Knudson et al., 2007
K. J. Knudson/A. E. Aufderheide/J. E. Buikstra, Seasonality and paleodiet in the Chiribaya polity of southern Peru. Journal of Archaeological Science 34, 2007, 451–462.

Koch et al., 1997
P. L. Koch/N. Tuross/M. L. Fogel, The effects of sample treatment and diagenesis on the isotopic integrity of carbonate in biogenic hydroxylapatite. Journal of Archaeological Science 24, 1997, 417–429.

Körper et al., in prep.
J. Körper/S. Wagner/U. Cubasch, Mediterranes Klima – Klimawandel in der Antike (in preparation).

Kohl, 2002
Ph. L. Kohl, Archaeological transformations: Crossing the pastoral/agricultural bridge. Iranica Antiqua 37, 2002, 151–190.

Kohl, 2007
Ph. L. Kohl, The making of Bronze Age Eurasia (Cambridge 2007).

Kohn, 1996
M. J. Kohn, Predicting animal $\delta^{18}O$: Accounting for diet and physiological adaption. Geochimica et Cosmochimica Acta 60, 1996, 4811–4829.

Kohn, 2004
M. J. Kohn, Comment on 'Tooth enamel mineralization in ungulates: Implications for recovering a primary isotopic time series' by B. H. Passey/T. E. Cerling, Geochimica et Cosmochimica Acta 68, 2004, 403–405.

Kohn et al., 1996
M. J. Kohn/M. J. Schoeninger/J. W. Valley, Herbivore tooth oxygen isotope composition: Effects of diet and physiology. Geochimica et Cosmochimica Acta 60, 1996, 3889–3896.

Kohn et al., 1998
M. J. Kohn/M. J. Schoeninger/J. W. Valley, Variability in oxygen isotope compositions of herbivore teeth: Reflections of seasonality or developmental physiology? Chemical Geology 152, 1998, 97–112.

Koryakova/Epimakhov, 2007
L. V. Koryakova/A. Epimakhov, The Urals and Western Siberia in the Bronze and Iron Ages (New York 2007).

Koryakova/Hanks, 2006
L. N. Koryakova/B. K. Hanks, Horse husbandry among early Iron Age trans-Ural societies. In: S. L. Olsen/S. Grant/A. M. Choyke/L. Bartosiewicz (Eds.), Horses and humans: The evolution of human-equine relationships. BAR International Series 1560 (Oxford 2006) 275–287.

Kossina, 1911
G. Kossina, Die Herkunft der Germanen. Zur Methode der Siedlungsarchäologie. Mannus-Bibliothek 6 (Würzburg 1911).

Kottwitz, 1971
G. Kottwitz, Psychologische Determinanten im Kontext der Wanderungsentscheidung. In: G. Kottwitz/M. Vanberg (Eds.), Ein Modell der Wanderungsentscheidung. (Berlin 1971/1972) 7–34.

Kremenetski, 1997
C. V. Kremenetski, The Late Holocene environmental and climate shift in Russia and surrounding lands. In: H. N. Dalfes/G. Kukla/H. Weiss (Eds.), Third millennium BC climate change and Old World collapse. NATO ASI Ser. I: Global Environmental Change 49 (Berlin 1997) 351–370.

Kremenetski, 2003
K. V. Kremenetski, Steppe and forest-steppe belt of Eurasia: Holocene environmental history. In: M. Levine/C. Renfrew/K. Boyle (Eds.), Prehistoric steppe adaption and the horse (Cambridge 2003) 11–27.

Kristiansen, 1989
K. Kristiansen, Prehistoric migrations: The case of the Single Grave and Corded Ware cultures. Journal of Danish Archaeology 8, 1989, 211–225.

Kristiansen/Larsson, 2005
K. Kristiansen/Th.B. Larsson, The rise of Bronze Age society. Travels, transmissions and transformations (Cambridge 2005).

Kröhnert, 2007
St. Kröhnert, Migration – Eine Einführung. Berlin – Institut für Bevölkerung und Entwicklung (2007). Available online: http://www.berlininstitut.org/fileadmin/user_upload/handbuch_texte/pdf_Kroehnert_Migration_Einfuehrung.pdf (accessed 12. 11. 2011).

Krueger/Sullivan, 1984
H. W. Krueger/Ch. H. Sullivan, Models for carbon isotope fractionation between diet and bone. In: J. R. Turnland/P. E. Johnson (Eds.), Stable isotope in nutrition. American Chemical Society Symposium Series 258, 1984, 205–220.

Kulcsár, 2009
G. Kulcsár, The beginning of the Bronze Age in the Carpathian basin (Budapest 2009).

Kutschera/Müller, 2003
W. Kutschera/W. Müller, 'Isotope' language of the Alpine Iceman investigated with AMS and MS. Nuclear instruments and methods in physics research section B: Beam interactions with materials and atoms 204, 2003, 705–719.

Lécolle, 1985
P. Lécolle, The oxygen isotope composition of landsnail shells as a climatic indicator: Applications to hydrogeology and palaeoclimatology. Chemical Geology 58, 1985, 157–181.

Lee, 1966
E. S. Lee, A theory of migration. Demography 3, 1966, 47–57.

Lee-Thorp, 2008
J.A. Lee-Thorp, On isotopes and old bones. Archaeometry 50/6, 2008, 925–950.

Lee-Thorp/Sponheimer, 2003
J. A. Lee-Thorp/M. Sponheimer, Three case studies used to reassess the reliability of fossil bone and enamel isotope signals for paleodietary studies. Journal of Anthropological Archaeology 22/3, 2003, 208–216.

Lee-Thorp/van der Merwe, 1991
J. Lee-Thorp/N. J. van der Merwe, Aspects of the chemistry of modern and fossil biological apatites. Journal of Archaeological Science 18, 1991, 343–354.

Lee-Thorp et al., 1989
J. A. Lee-Thorp/J. C. Sealy/N. J. van der Merwe, Stable carbon isotope ratio differences between bone collagen and bone apatite, and their relationship to diet. Journal of Archaeological Science 16, 1989, 585–599.

Lee-Thorp et al., 1993
J. A. Lee-Thorp/J. C. Sealy/A. G. Morris, Isotopic evidence for diets of prehistoric farmers in South Africa. In: J. B. Lambert/G. Grupe (Eds.), Prehistoric human bone – archaeology at the molecular level (Berlin/Heidelberg 1993) 99–120.

Levine, 1982
M. A. Levine, The use of crown height measurements and eruption-wear sequences to age horse teeth. In: B. Wilson/C. Grigson/S. Payne, (Eds.), Ageing and sexing animal bones from archaeological sites, BAR International Series 109 (Oxford 1982) 223–250.

Levine, 1999
M. A. Levine, Botai and the origins of horse domestication. Journal of Anthropological Archaeology 18, 1999, 29–78.

Levine, 2004
M. A. Levine, Exploring the criteria for early horse domestication. In: M. Jones (Ed.), Traces of ancestry. Studies in honour of Colin Renfrew (Cambridge 2004) 115–126.

Levinson et al., 1987
A. A. Levinson/B. Luz/Y. Kolodny, Variations in oxygen isotopic compositions of human teeth and urinary stones. Applied Geochemistry 2, 1987, 367–371.

Lichardus, 1988
J. Lichardus, Der Westpontische Raum und die Anfänge der kupferzeitlichen Zivilisation. In: A. Fol/J. Lichardus (Eds.), Macht, Herrschaft und Gold. Das Gräberfeld von Varna (Bulgarien) und Anfänge einer neuen europäischen Zivilisation (Saarbrücken 1988) 79–130.

Lichardus/Lichardus-Itten, 1995
J. Lichardus/M. Lichardus-Itten, Nordpontische Beziehungen während der frühen Urgeschichte Bulgariens. Thracia 11, 1995, 31–62.

Lichardus/Lichardus-Itten, 1998
J. Lichardus/M. Lichardus-Itten, Nordpontische Beziehungen und ihre westlichen Nachbarn: Ein Beitrag zur Entstehung der frühen Kupferzeit Alteuropas. In: B. Hänsel/J. Machnik (Eds.), Das Karpatenbecken und die osteuropäische Steppe. Nomadenbewegung und Kulturaustausch in den vorchristlichen Metallzeiten (4000–500 v. Chr.). Südosteuropa-Schriften 20, Prähistorische Archäologie in Südosteuropa 12 (München/Rahden (Westf.) 1998) 99–122.

Lillie, 1998
M. C. Lillie, The Dnieper Rapids region of Ukraine: A consideration of chronology, dental pathology and diet at the Mesolithic–Neolithic transition. PhD thesis, University of Sheffield 1998.

Lillie, 2003
M. C. Lillie, Tasting the forbidden fruit: Gender based dietary differences among prehistoric hunter-gatherers of Eastern Europe? Before Farming 2 (3), 2003, 1–16.

Lillie/Budd, 2011
M. C. Lillie/Ch. Budd, The Mesolithic–Neolithic transition in Eastern Europe: Integrating stable isotope studies of diet with palaeopathology to identify subsistence strategies and economy. In: R. Pinhasi/J. Stock (Eds.), Human bioarchaeology of the transition to agriculture (New York 2011) 43–62.

Lillie/Jacobs, 2006
M. C. Lillie/K. Jacobs, Stable isotope analysis of fourteen individuals from the Mesolithic cemetery of Vasilyevka II, Dnieper Rapids region, Ukraine. Journal of Archaeological Science 33, 2006, 880–886.

Lillie/Richards, 2000
M. C. Lillie/M. Richards, Stable isotope analysis and dental evidence of diet at the Mesolithic-Neolithic transition in Ukraine. Journal of Archaeological Science 27, 2000, 965–972.

Lillie et al., 2003
M. C. Lillie/M. P. Richards/K. Jacobs, Stable isotope analysis of twenty-one individuals from the Epipalaeolithic cemetery of Vasilyevka III, Dnieper Rapids region, Ukraine. Journal of Archaeological Science 30, 2003, 743–752.

Lillie et al., 2009
M. C. Lillie/Ch. E. Budd/I. D. Potekhina/R. E. M. Hedges, The radiocarbon reservoir effect: New evidence from the cemeteries of the Middle and Lower Dnieper Basin, Ukraine. Journal of Archaeological Science 36, 2009, 256–264.

Lilli et al., 2011
M. Lillie/Ch. Budd/I. Potekhina, Stable isotope analysis of prehistoric populations from the cemeteries of the Middle and Lower Dnieper Basin, Ukraine. Journal of Archaeological Science 38, 2011, 57–68.

Lillie et al., 2012
M. Lillie/I. Potekhina/Ch. Budd/A. G. Nikitin, Prehistoric populations of Ukraine: Migration at the later Mesolithic to Neolithic transition. In: E. Kaiser/J. Burger/W. Schier (Eds.), Population dynamics in prehistory and early history. New approaches using stable isotopes and genetics. Topoi. Berlin Studies of the Ancient World 5 (Berlin 2012) 77–92.

Longinelli, 1984
A. Longinelli, Oxygen isotopes in mammal bone phosphate: A new tool for palaeohydrological and palaeoclimatological research. Geochimica et Cosmochimica Acta 48, 1984, 385–390.

Longinelli/Nuti, 1973
A. Longinelli/S. Nuti, Oxygen isotope measurements of phosphate from fish teeth and bones. Earth and Planetary Science Letters 20, 1973, 337–340.

Longinelli/Peretti Padalino, 1980
A. Longinelli/A. Peretti Padalino, Oxygen isotope composition of water from mammal blood: first results. Mass Spectrometry in Biochemical Medical and Environmental Research 1, 1980, 135–139.

Longinelli et al., 2003
A. Longinelli/P. Iacumin/S. Davanzo/V. Nikolaev, Modern reindeer and mice: Revised phosphate–water isotope equations. Earth and Planetary Science Letters 214, 2003, 491–498.

Longinelli et al., 2006
A. Longinelli/E. Anglesio/O. Flora/P. Iacumin/E. Selmo, Isotopic composition of precipitation in Northern Italy: Reverse effect of anomalous climatic effects. Journal of Hydrology 329, 2006, 471–476.

Lowenstam/Weiner, 1989
H. A. Lowenstam/S. Weiner, On biomineralization (New York/Oxford 1989).

Lübke et al., 2009
H. Lübke/F. Lüth/Th. Terberger, Fishers or farmers? The archaeology of the Ostorf cemetery and related Neolithic finds in the light of the new data. In: L. Larsson/F. Lüth/T. Terberger (Eds.), Innovation and continuity – Non-Megalithic mortuary practices in the Baltic. New methods and research into the Development of Stone Age society.International workshop at Schwerin on 24–26 March 2006. Bericht der Römisch-Germanischen Kommission 88 (Mainz 2009) 307–338.

Ludwig et al., 2009
A. Ludwig/M. Pruvot/M. Reissmann/N. Benecke/G.A. Brockmann/P. Castaños/M. Cieslak/S. Lippold/L. Llorente/A.-S. Malaspinas/M. Slatkin/M. Hofreiter, Coat color variation at the beginning of horse domestication. Science 324, 2009, 485.

Luz/Kolodny, 1985
B. Luz/Y. Kolodny, Oxygen isotope variations in phosphate of biogenic apatites, IV. Mammal teeth and bones. Earth Planetary Science Letters 75, 1985, 29–36.

Luz et al., 1984
B. Luz/Y. Kolodny/M. Horowitz. Fractionation of oxygen isotopes between mammalian bone-phosphate and environmental drinking water. Geochimica et Cosmochimica Acta 48, 1984, 1689–1693.

Luz et al., 1990
B. Luz/A. B. Cormie/H. P. Schwarcz, Oxygen isotope variations in phosphate of deer bones: Geochimica et Cosmochimica Acta 54, 1990, 1723–1728.

Mallory, 1989
J. P. Mallory, In search of the Indo-Europeans (London 1989).

Mansheev, 2009
D. M. Mansheev, Forms of nomadism and livestock management of the eastern Sayan Buryats in the late 19th and early 20th centuries. Archaeology, Ethnology and Anthropology of Eurasia 37/2, 2009, 104–109.

Manzura, 1994
I. Manzura, Cultural groups from the steppes of eastern Europe in the Eneolithic period and Early Bronze Age. Oxford Journal of Archaeology 13 (3), 1994, 265–277.

Mashkour, 2003
M. Mashkour, Tracing ancient 'nomads': Isotopic research on the origins of vertical 'transhumance' in the Zagros region. Nomadic Peoples NS 7, 2003, 36–47.

Maurer et al., 2012
A.-F. Maurer/S. J. G. Galer/C. Knipper/L. Beierlein/E. V. Nunn/D. Peters/Th. Tütken/K. W. Alt/B. R. Schöne, Bioavailable 87Sr/86Sr in different environmental samples – Effects of anthropogenic contamination and implications for isoscapes in past migration studies. Science of the Total Environment 433, 2012, 216–229.

Melyukova, 1995
A. I. Melyukova, Scythians of Southeastern Europe. In: J. Davis-Kimball/V. A. Bashilov/L. T. Yablonsky (Eds.), Nomads of the Eurasian steppes in the Early Iron Age (Berkeley, CA 1995) 27–62.

Menghin/Parzinger, 2007
W. Menghin/H. Parzinger, Vorwort der Herausgeber. In: W. Menghin/H. Parzinger (Eds.), Im Zeichen des goldenen Greifen. Königsgräber der Skythen (München/London/New York 2007) 23–25.

van der Merwe, 1982
N. J. van der Merwe, Carbon isotopes, photosynthesis, and archaeology. American Scientist 70, 1982, 596–606.

van der Merwe/Medina, 1991
N. J. van der Merwe/E. Medina, The canopy effect, carbon isotope ratios and foodwebs in Amazonia. Journal of Archaeological Science 18/3, 1991, 249–259.

van der Merwe/Vogel, 1978
N. J. van der Merwe/J. C. Vogel, 13C content of human collagen as a measure of prehistoric diet in the Woodland North America. Nature 276, 1978, 815–816.

Mignon, 1993
M. R. Mignon, Dictionary of concepts in archaeology (London 1993).

Molodin/Polos'mak, 2007
V. I. Molodin/N. V. Polos'mak, Die Denkmäler auf dem Ukok-Plateau. In: W. Menghin/H. Parzinger (Eds.), Im Zeichen des goldenen Greifen. Königsgräber der Skythen (München/London/New York 2007) 140–147.

Molodin/Parzinger/Ceveendorž, 2007
V. I. Molodin/H. Parzinger/D. Ceveenzorž, Das Kriegergrab von Olon-Kurin-Gol. In: W. Menghin/H. Parzinger (Eds.), Im Zeichen des goldenen Greifen. Königsgräber der Skythen (München/London/New York 2007) 148–155.

Montgomery, 2002
J. Montgomery, Lead and strontium isotope compositions of human dental tissues as an indicator of ancient exposure and population dynamics. PhD thesis, University of Bradford 2002.

Montgomery et al., 2003
J. Montgomery/J. A. Evans/T. Neighbour, Sr isotope evidence for population movement within the Hebridean Norse community of NW Scotland. Journal of the Geological Society 160 (5), 2003, 649–653.

Montgomery et al., 2005
J. Montgomery/J. A. Evans/D. Powlesland/C. Roberts, Continuity or colonization in Anglo-Saxon England? Isotope evidence for mobility, subsistence practice and status at West Heslerton. American Journal of Physical Anthropology 126, 2005, 123–138.

Montgomery et al., 2007
J. Montgomery/R. E. Cooper/J. A. Evans, Foragers, farmers or foreigners? An assessment of dietary strontium isotope variation in Middle Neolithic and Early Bronze Age East Yorkshire. In: M. Larsson/M. Parker Pearson (Eds.), From Stonehenge to the Baltic. Living with cultural diversity in the third millennium BC (Oxford 2007) 65–75.

Moshkova, 1995
M. G. Moshkova, A brief review of the history of the Sauromatian and Sarmatian tribes. In: J. Davis-Kimball/V. A. Bashilov/L. T. Yablonsky (Eds.), Nomads of the Eurasian steppes in the Early Iron Age (Berkeley, CA 1995) 85–90.

Motuzaite-Matuzeviciute et al., 2009
G. Motuzaite-Matuzeviciute/H. V. Hunt/M. K. Jones, Multiple sources for Neolithic European agriculture: Geographical origins of early domesticates in Moldova and Ukraine. In: P. M. Dolukhanov/G. R. Sarson/A. M. Shukurov (Eds.), The East European Plain on the eve of agriculture. BAR International Series 1964 (Oxford 2009) 45–51.

Müldner/Richards, 2005
G. Müldner/M. P. Richards, Fast or feast: Reconstructing diet in later medieval England by stable isotope analysis. Journal of Archaeological Science 32, 2005, 39–48.

Müldner/Richards, 2007
G. Müldner/M. P. Richards, Stable isotope evidence for 1500 years of human diet at the city of York, UK. American Journal of Physical Anthropology 133, 2007, 682–697.

Müller et al., 2003
W. Müller/H. Fricke/A. N. Halliday/M. T. McCulloch/J.-A. Wartho, Origin and migration of the Alpine iceman. Science 302, 2003, 862–866.

Myhre/Myhre, 1972
B. M. Myhre/B. Myhre, The concept "immigration" in archaeological contexts illustrated by examples from

West Norwegian and North Norwegian Early Iron Age. Norwegian Archaeological Review 5, 1972, 45–70.

Naliwikin, 1959
D. W. Naliwikin, Kurzer Abriss der Geologie der UdSSR. Fortschritte der sowjetischen Geologie 2 (Berlin 1959).

Nehlich et al., 2009
O. Nehlich/J. Montgomery/J. Evans/S. Schade-Lindig/S. L. Pichler/M. P. Richards/K. W. Alt, Mobility or migration: A case study from the Neolithic settlement of Nieder-Mörlen (Hessen, Germany). Journal of Archaeological Science 36, 2009, 1791–1799.

Nehlich et al., 2010
O. Nehlich/D. Borić/S. Stefanović/M. P. Richards, Sulphur isotope evidence for freshwater fish consumption: A case study from the Danube Gorges, SE Europe. Journal of Archaeological Science 37, 2010, 1131–1139.

Nechoroschew, 1966
W. P. Nechoroschew, Geologie des Altai. Fortschritte der sowjetischen Geologie 7 (Berlin 1966).

Neustupný, 1981
E. Neustupný, Mobilität der äneolithischen Populationen. Slovenská Archeológia 29/1, 1981, 111–119.

Neustupný, 1983
E. Neustupný, The demography of prehistoric cemeteries. Památky Archeologické 74, 1983, 7–34.

Nielsen-Marsh/Hedges, 2000
C. M. Nielsen-Marsh/R. E. M. Hedges, Patterns of diagenesis in bone II. Effects of acetic acid treatment and the removal of diagenetic CO_3^{2-}. Journal of Archaeological Science 27, 2000, 1151–1159.

L. Nikolova, 1999
L. Nikolova, The Balkans in later prehistory. Periodization, chronology and cultural development in the Final Copper Age and Early Bronze Age (4th and 3rd millennia BC). BAR International Series 791 (Oxford 1999).

Nikolova, 2006a
A. V. Nikolova, Der Beginn der Errichtung von Grabhügeln. In: K. P. Bunjatjan/E. Kaiser/A. V. Nikolova (Eds.), Bronzezeitliche Bestattungen aus dem Unteren Dneprgebiet. Schriften des Zentrums für Archäologie und Kulturgeschichte des Schwarzmeerraumes 8 (Langenweißbach 2006) 5–12.

Nikolova, 2006b
A. V. Nikolova, Die Bestattungen der Jamnaja-Kultur. In: K. P. Bunjatjan/E. Kaiser/A. V. Nikolova (Eds.), Bronzezeitliche Bestattungen aus dem Unteren Dneprgebiet. Schriften des Zentrums für Archäologie und Kulturgeschichte des Schwarzmeerraumes 8 (Langenweißbach 2006) 13–32.

Nikolova/Kaiser, 2009
A. V. Nikolova/E. Kaiser, Die absolute Chronologie der Jamnaja-Kultur im nördlichen Schwarzmeergebiet auf der Grundlage erster chronologischer Daten. Eurasia Antiqua 15, 2009, 205–236.

O'Connell/Hedges, 1999
T. C. O'Connell/R. E. M. Hedges, Investigations into the effects of diet on modern human hair isotopic values. American Journal of Physical Anthropology 108, 1999, 409–425.

O'Connell et al., 2003
T. O'Connell/M. Levine/R. Hedges, The importance of fish in the diet of central Eurasian peoples from the Mesolithic to the Early Iron Age. In: M. Levine/C. Renfrew/K. Boyle (Eds.), Prehistoric steppe adaption and the horse (Cambridge 2003) 253–268.

O'Leary, 1988
M. H. O'Leary, Carbon isotopes in photosynthesis. BioScience 38/5, 1988, 328–336.

Oelze, 2012
V. M. Oelze, Mobility and diet in Neolithic, Bronze Age and Iron Age Germany – Evidence from multiple isotope analysis. PhD thesis University of Leiden, Leiden 2012. Available online: https://openaccess.leidenuniv.nl/handle/1887/19045 (accessed 10. 11. 2013).

Olsen, 2006
S. L. Olsen, Early horse domestication: Weighing the evidence. In: S. L. Olsen/S. Grant/A. Choyke/L. Bartosiewicz (Eds.), Horses and humans. The evolution of the human-equid relationships. BAR International Series 1560 (Oxford 2006) 81–113.

Otchir-Gorieva, 2002
M. Otchir-Gorieva, Welchen Kultur- und Wirtschaftstyp repräsentieren die bronzezeitlichen Funde in den Wolga-Manyc-Steppen? Eurasia Antiqua 8, 2002, 103–133.

Otroschenko, 2010
V. Otroschenko, Die Katakombengrab-Kultur. In: J. Leskovar/M-Ch. Zingerle (Eds.), Goldener Horizont. 4000 Jahre in der Ukraine (Weitra 2010) 30–33.

Outram et al., 2009
A. K. Outram/N. A. Stear/R. Bendrey/S. Olsen/A. Kasparov/V. Zaibert/N. Thorpe/R. P. Evershed, The earliest horse harnessing and milking. Science 323/5919, 2009, 1332–1335.

Palmer/Edmond, 1989
M. R. Palmer/J. M. Edmond, The strontium isotope budget of the modern ocean. Earth and Planetary Science Letters 92 (1), 1989, 11–26.

Panayotov, 1989
I. Panayotov, Zur Chronologie und Periodisierung der Bronzezeit in den heutigen Bulgarischen Gebieten. Thrakia 9, 1989, 74–103.

Parzinger, 1993
H. Parzinger, Studien zur Chronologie und Kulturgeschichte der Jungstein-, Kupfer- und Frühbronzezeit zwischen Karpaten und Mittlerem Taurus. Römisch-Germanische Forschungen 52 (Mainz 1993).

Parzinger, 1998
H. Parzinger, Kulturverhältnisse in der eurasischen Steppe während der Bronzezeit. In: B. Hänsel (Eds.), Mensch und Umwelt in der Bronzezeit Europas. Man and Environment in Bronze Age Europe (Kiel 1998) 457–479.

Parzinger, 2004
H. Parzinger, Die Skythen (München 2004).

Parzinger, 2006
H. Parzinger, Die frühen Völker Eurasiens: Vom Neolithikum bis zum Mittelalter (München 2006).

Parzinger, 2007
H. Parzinger, Die Reiternomaden der eurasischen Steppe während der Skythenzeit. In: W. Menghin/H. Parzinger (Eds.), Im Zeichen des goldenen Greifen. Königsgräber der Skythen (München/London/New York 2007) 30–48.

Parzinger, 2009
H. Parzinger, Die frühen Reiternomaden der eurasischen Steppe: Neue Lebens- und Gesellschaftsformen zwischen Jenissei und Unterer Donau. In: W. Seipel (Eds.), Das Gold der Steppe. Fürstengräber jenseits des Alexanderreichs (Wien 2009) 16–29.

Parzinger, 2010
H. Parzinger, Die Skythen der ukrainischen Steppe und ihre Stellung in der Welt der eurasischen Reiternomaden. In: J. Leskovar/M-Ch. Zingerle (Eds.), Goldener Horizont. 4000 Jahre in der Ukraine (Weitra 2010) 58–66.

Parzinger/Nagler, 2007
H. Parzinger/A. Nagler, Die ersten Reiternomaden: Der Beginn einer neuen Epoche. In: W. Menghin/H. Parzinger (Eds.), Im Zeichen des goldenen Greifen. Königsgräber der Skythen (München/London/New York 2007) 60–68.

Pashkevich, 2003
G. A. Pashkevich, Palaeoethnobotanical evidence of agriculture in the steppe and forest-steppe of east Europe in the late Neolithic and Bronze Age. In: M. Levine/C. Renfrew/K. Boyle (Eds.), Prehistoric steppe adaptation and the horse (Cambridge 2003) 287–298.

Pashkevich/Gerasimenko, 2009
G. A. Pashkevich/N. P. Gerasimenko, The Holocene vegetation, climate and early human subsistence in the Ukraine. In: P. M. Dolukhanov/G. R. Sarson/A. M. Shukurov (Eds.), The East European Plain on the eve of agriculture. BAR International Series 1964 (Oxford 2009) 45–51.

Pellegrini et al., 2008
M. Pellegrini/R. E. Donahue/C. Chenery/J. Evans/J. Lee-Thorp/J. Montgomery/M. Mussi, Faunal migration in late-glacial central Italy: implications for human resource exploitation. Rapid Communications in Mass Spectrometry 22, 2008, 1714–1726.

Pernicka et al., 1997
E. Pernicka/F. Bergemann/S. Schmitt-Strecker/H. Todorova/I. Kuleff, Prehistoric copper in Bulgaria: Its composition and provenance. Eurasia Antiqua 3, 1997, 41–180.

Petersen, 1958
W. Petersen, A general typology of migration. American Sociological Reviev 23 (3), 1958, 256–266.

Petersen, 1972
W. Petersen, Eine allgemeine Typologie der Wanderung. In: G. Széll (Ed.), Regionale Mobilität. Nymphenburger Texte zur Wissenschaft 10 (München 1972) 95–114.

Petrenko, 1995
V. G. Petrenko, Scythian culture in the North Caucasus. In: J. Davis-Kimball/V. A. Bashilov/L. T. Yablonsky (Eds.), Nomads of the Eurasian steppes in the Early Iron Age (Berkeley, CA 1995) 5–26.

van der Plicht, 2004
J. van der Plicht, Radiocarbon, the calibration curve and Scythian chronology. In: E. M. Scott/A. Yu. Alekseev/G. Zaitseva (Eds.), Impact of the environment on human migration in Eurasia. IV Earth and Environmental Sciences 42 (Dordrecht et al. 2004) 45–61.

van der Plicht et al., 2006
J. van der Plicht/N. I. Shishlina/R. E. M. Hedges/E. P. Zazovskaya/V. S. Sevastianov/O. A. Chichagova, Reservoir Effect and ^{14}C Chronology of the Catacomb cultures of the North-West Caspian Steppe Area: A case study. Eurasia Antiqua 12, 2006, 113–126.

Poage/Chamberlain, 2001
M. A. Poage/C. P. Chamberlain, Empirical relationships between elevation and the stable isotope composition of precipitation and surface waters: Considerations for studies of paleoelevation change. American Journal of Science, 301, 2001, 1–15.

Polin, 2007
S. V. Polin, Fürstenkurgane in der ukrainischen Steppenzone. In: W. Menghin/H. Parzinger (Eds.), Im Zeichen des goldenen Greifen. Königsgräber der Skythen (München/London/New York 2007) 256–267.

Polin/Daragan, 2011
S. Polin/M. Daragan, Das Prunkgrab Alexandropol'-Kurgan. Vorbericht über die Untersuchungen in den Jahren 2004–2009. Eurasia Antiqua 17, 2011, 189–214.

Pollard et al., 2011a
A. M. Pollard/M. Pellegrini/J. A. Lee-Thorp, Technical note: Some observations on the conversion of dental enamel $\delta^{18}O_p$ values to $\delta^{18}O_w$ to determine human mobility. American Journal of Physical Anthropology 145(3), 2011, 499–504.

Pollard et al., 2011b
A. M. Pollard/P. Ditchfield/J. S. O. McCullagh/T. G. Allen/M. Gibson/C. Boston/S. Clough/N. Marquez-Grant/R. A. Nicholson, 'These boots were made for walking': The isotopic analysis of a C4 Roman inhumation from Gravesend, Kent, UK. American Journal of Physical Anthropology 146, 2011, 446–456.

Pollex, 1997
A. Pollex, Ein neolithisches Rinderskelett von Penkun, Lkr. Uecker-Randow. Bemerkungen zur Interpretation sogenannter Rinderbestattungen. Jahrbuch zur Bodendenkmalpflege in Mecklenburg-Vorpommern 45, 1997, 103–128.

Pollex, 1999
A. Pollex, Comments on the interpretation of the so-called cattle burials of Neolithic Central Europe. Antiquity 73, 1999, 542–550.

Popova, 2009
L. M. Popova, Blurring the Boundaries. Foragers and pastoralists in the Volga-Ural region. In: B. K. Hanks/K. M. Linduff (Eds.), Social complexity in prehistoric Eurasia. Monuments, metals, and mobility (Cambridge/New York etc. 2009) 296–320.

Povalahev, 2008
N. Povalahev, Die Griechen am Nordpontos. Die nordpontische Kolonisation im Kontext der Großen Griechischen Kolonisationsbewegung vom 8. bis 6. Jahrhundert v. Chr. Quellen und Forschungen zur Antiken Welt 53 (München 2008).

Price, 2006
T. D. Price, The first settlers of Iceland: An isotopic approach to colonisation. Antiquity 80, 2006, 130–144.

Price, 2007
T. D. Price, Principles in archaeology (Boston, Mass. et al. 2007).

Price et al., 1994
T. D. Price/C. M. Johnson/J. A. Ezzo/J. Ericson/J. H. Burton, Residential mobility in the prehistoric southwest United States: A preliminary study using strontium isotope analysis, Journal of Archaeological Science, 21, 1994, 315–330.

Price et al., 2000
T. D. Price/L. Manzanilla/W. D. Middleton, Immigration and the ancient city of Teotihuacan in Mexico: A study using strontium isotope ratios in human bone and teeth. Journal of Archaeological Science 27, 2000, 903–913.

Price et al., 2001
T. D. Price/R. A. Bentley/J. Lüning/D. Gronenborn/J. Wahl, Human migration in the Linearbandkeramik of central Europe. Antiquity 75, 2001, 593–603.

Price et al., 2002
T. D. Price/J. H. Burton/R. A. Bentley, The characterization of biologically available strontium isotope ratios for the study of prehistoric migration. Archaeometry 44/1, 2002, 117–135.

Price et al., 2004
T. D. Price/C. Knipper/G. Grupe/V. Smrcka, Strontium isotopes and prehistoric migration: The bell beaker period in central Europe. European Journal of Archaeology 7/1, 2004, 9–40.

Price et al., 2007a
T. D. Price/J. H. Burton/J. B. Stoltman, Place of origin of prehistoric inhabitants of Aztalan, Jeffersen Co., Wisconsin. American Antiquity 73, 2007, 524–538.

Price et al., 2007b
T. D. Price/S. H. Ambrose/P. Bennike/J. Heinemeier/N. Noe-Nygaard/E. B. Petersen/P. V. Petersen/M. P. Richards, New information on the Stone Age graves at Dragsholm, Denmark. Acta Archaeologica 78, 2007, 193–219.

Price et al., 2008
T. D. Price/K. Bokelmann/A. Pike-Tay, Late Paleolithic reindeer on the north European Plain. In: Z. Sulgostowska/A. J. Tomaszewski (Eds.), Man – millennia – environment. Studies in honour of Romuald Schild (Warsaw 2008) 123–131.

Price et al., 2010
T. D. Price/J. H. Burton/R. J. Sharer/J. E. Buikstra/L. E. Wright/L. P. Traxler/K. A. Miller, Kings and commoners at Copan: Isotopic evidence for origins and movements in the Classic Maya period. Journal of Anthropological Archaeology 29, 2010, 15–32.

Prien, 2005
R. Prien, Archäologie und Migration. Universitätsforschungen zur Prähistorischen Archäologie 120 (Bonn 2005).

Privat, 2002
K. Privat, Preliminary report of paleodietary analysis of human and faunal remains from Bolshekaraganski kurgan 25. In: V. T. Kovaleva/G. B. Zdanovich (Eds.), Arkaim: Nekropol (po materialam kurgana 25 Bol'shekaraganskoe Mogil'nika) (Chelyabinsk 2002) 167–171.

Privat, 2004
K. Privat, Palaeoeconomy of the Eurasian Steppe: Biomolecular studies. PhD thesis, University of Oxford 2004.

Privat et al., 2007
K. L. Privat/T. C. O'Connell/R. E. M. Hedges, The distinction between freshwater- and terrestrial-based diets: Methodological concerns and archaeological applications of stable sulphur isotope analysis. Journal of Archaeological Science 34, 2007, 1197–1204.

Prowse et al., 2004
T. L. Prowse/H. P. Schwarcz/S. R. Saunders/R. Macchiarelli/L. Bondioli, Isotopic paleodiet studies of skeletons from the Imperial Roman-age cemetery of Isola Sacra, Italy. Journal of Archaeological Science 31, 2004, 259–272.

Prowse et al., 2005
T. L. Prowse/H. P. Schwarcz/S. R. Saunders/R. Machiarelli, L. Bondioli, Isotopic evidence for age-related variation in diet from Isola Sacra, Italy. American Journal of Physical Anthropology 128, 2005, 2–13.

Pruvost et al., 2011
M. Pruvost/R. Bellone/N. Benecke/E. Sandoval-Castellanos/M. Cieslak/T. Kuznetsova/A. Morales-Muñiz/T. O'Connor/M. Reissmann/M. Hofreiter/A. Ludwig, Genotypes of predomestic horses match phenotypes painted in Paleolithic works of cave art. Proceedings of the National Academy of Sciences 108 (46), 2011, 18626–18630.

Pustovalov, 1994
S. Z. Pustovalov, Economy and social organization of Northern Pontic steppe – forest-steppe pastoral populations: 2700–2000 BC (Catacomb culture). Baltic-Pontic Studies 2, 1994, 86–134.

Rassamakin, 1999
Y. Ya. Rassamakin, The Eneolithic of the Black Sea steppe: Dynamics of cultural and economic development 4500–2300 BC. In: M. Levine/Y. Rassamakin/A. Kislenko/N. Tatarintseva (Eds.), Late prehistoric exploitation of the Eurasian steppe (Cambridge 1999) 59–182.

Rassamakin, 2004
J. J. Rassamakin, Die nordpontische Steppe in der Kupferzeit. Gräber aus der Mitte der 5. Jts. bis Ende des 4. Jts. v. Chr. Archäologie in Eurasien 17 (Berlin 2004).

Rassamakin, 2011
Y. Ya. Rassamakin, Eneolithic burial mounds in the Black Sea steppe. From the first burial symbols to monumental ritual architecture. In: E. Borgna/S. Müller-Celka (Eds.), Ancestral landscapes: Burial mounds in the Copper and Bronze ages (Central and Eastern Europe – Balkans – Adriatic – Aegean, 4th–2nd millennium BC). International Conference, Udine/Italy, May 15th–18th 2008. Travaux de la Maison de l'Orient et de la Méditerranée 58 (Lyon 2011) 293–306.

Rassamakin/Nikolova, 2008
Y. Ya. Rassamakin/A. V. Nikolova, Carpathian imports and imitations in context of the Eneolithic and Early Bronze Age of the Black Sea steppe area. In: P. F. Biehl/Y. Ya. Rassamakin (Eds.), Import and imitation in archaeology. Schriften des Zentrums für Archäologie und Kulturgeschichte des Schwarzmeerraumes 11 (Langenweißbach 2008) 51–87.

Ratzel, 1899
F. Ratzel, Anthropogeographie (Stuttgart 1899).

Ravenstein, 1885
E. G. Ravenstein, The laws of migration. Journal of the Royal Statistical Society 48, 1885, 167–227.

Ravenstein, 1889
E. G. Ravenstein, The laws of migration. Journal of the Royal Statistical Society 52, 1889, 241–305.

Reitemeier et al., 2006
B. Reitemeier/N. Schwenzer/M. Ehrenfeld, Einführung in die Zahnmedizin (Stuttgart 2006).

Reitsema et al., 2010
L. J. Reitsema/D. E. Crews/M. Polcyn, Preliminary evidence for medieval Polish diet from carbon and nitrogen stable isotopes. Journal of Archaeological Science 37, 2010, 1413–1423.

Renfrew, 1972
C. Renfrew, The emergence of civilisation (London 1972).

Renfrew, 1973
C. Renfrew, Before civilisation. The radiocarbon revolution and prehistoric Europe (London 1973).

Renfrew, 2009
C. Renfrew, From myth to method. Advances in the archaeology of the Eurasian steppe. In: B. K. Hanks/K. M. Linduff (Eds.), Social complexity in prehistoric Eurasia. Monuments, metals, and mobility (Cambridge/New York etc. 2009) Foreword.

Reynard/Hedges, 2008
L. M. Reynard/R. E. M. Hedges, Stable hydrogen isotopes of bone collagen in palaeodietary and palaeoenvironmental reconstruction. Journal of Archaeological Science 35, 2008, 1934–1942.

Richards/Hedges, 1999
M. P. Richards/R. E. M. Hedges, Stable isotopic evidence for similarities in the types of marine foods used by Late Mesolithic humans at sites along the Atlantic Coast of Europe, Journal of Archaeological Science 26, 1999, 717–722.

Richards et al., 1998
M. P. Richards/R. E. M. Hedges/T. I. Molleson/J. C. Vogel, Stable isotope analysis reveals variations in human diet at the poundbury camp cemetery site. Journal of Archaeological Science 25, 1998, 1247–1252.

Richards et al., 2000
M. P. Richards/R. E. M. Hedges/R. Jacobi, Gough's Cave and Sun Hole Cave human stable isotope values indicate a high animal protein diet in the British Upper Palaeolithic. Journal of Archaeological Science 27, 2000, 1–3.

Richards et al., 2001
M. P. Richards/P. B. Pettitt/M. C. Stiner/E. Trinkaus, Stable isotope evidence for increasing dietary breadth in the European mid-Upper Paleolithic. Proceedings of the National Academy of Science, USA 98/11, 2001, 6528–6532.

Rolle, 1972
R. Rolle, Neue Ausgrabungen skythischer und sakischer Grabanlagen in der Ukraine und in Kazachstan. Prähistorische Zeitschrift 47, 1972, 47–77.

Rolle, 1978
R. Rolle, Totenkult der Skythen. Teil I: Das Steppengebiet (Berlin/New York 1978).

Rolle et al., 1996
R. Rolle/V. Ju. Murzin/B. A. Šramko, Das Burgwallsystem von Bel'sk (Ukraine). Eine frühe stadtartige Anlage im skythischen Landesinneren. Hamburger Beiträge zur Archäologie 18, 1991, 1996, 57–84.

Roth, 2007
K. Roth, What's in a region? Southeast Europe regions between globalization, EU-Integration and marginalization, in: K. Roth/U. Brunnbauer (Eds.), Region, regional identity and regionalism in Southeast Europe, part I. Ethnologia Balkanica 11, 2007, 17–42.

Rouse, 1958
B. I. Rouse, The inference of migrations from anthropological evidence. In: R. H. Thompson (Ed.), Migrations in New World culture history. University of Arizona Social Science Bulletin 27 (Tucson, AZ 1958) 63–68.

Rouse, 1986
B. I. Rouse, Migrations in prehistory: Inferring population movement from cultural remains (New Haven, CT 1986).

Rozanski et al., 1993
K. Rozanski/L. Araguás-Araguás/R. Gonfiantini, Isotopic patterns in modern global precipitation. In: P. K. Swart/K. C. Lohmann/J. McKenzie/S. Savin (Eds.), Climate change in continental isotope records. Geophysical Monographs 78 (Washington, DC 1993) 1–36.

Rudenko, 1969
S. I. Rudenko, Studien über das Nomadentum. In: L. Földes (Ed.): Viehwirtschaft und Hirtenkultur. Ethnografische Studien (Budapest 1969) 15–32.

Salzmann, 2002
P. C. Salzmann, Pastoral nomads. Some general observations based on research in Iran. Journal of Anthropological Research 58/2, 2002, 245–264.

Samashev et al., 2000
Z. Samashev/G. Bazarbaeva/G. Zhumabekova/S. Sungatai, Berel' (Almaty 2000).

Samašev et al., 2002
Z. S. Samašev/G. A. Bazarbaeva/G. S. Žumabekova, Die "goldhütenden Greife" des Herodot und die archäologische Kultur der frühen Nomaden im kazachischen Altai. Skythenzeitliche Kurgane von Berel' und Tar Asu. Eurasia Antiqua 8, 2002, 237–276.

Samašev, 2007
Z. Samašev, Die Fürstengräber von Berel'. In: W. Menghin/H. Parzinger (Eds.), Im Zeichen des goldenen Greifen. Königsgräber der Skythen (München/London/New York 2007) 132–139.

Samashev, 2011
Z. Samashev, Berel' (Almaty 2011).

Sanchez Chillon et al., 1994
B. Sanchez Chillon/M. Alberdi/F. P. Bonadonna/G. Stenni/A. Longinelli, Oxygen isotopic composition of fossil equid tooth and bone phosphate: An archive of difficult interpretation. Palaeogeography, Palaeoclimatology, Palaeoecology 107, 1994, 317–328.

Schatz/Stephan, 2008
K. Schatz/E. Stephan, Archäozoologie der frühkeltischen Faunenfunde. Studien zur Wirtschaftsgeschichte im Umfeld frühkeltische Fürstensitze. In: D. Krausse (Ed.), Frühe Zentralisierungs- und Urbanisierungsprozesse. Zur Genese und Entwicklung frühkeltischer Fürstensitze und ihres territorialen Umlandes. Kolloquium des DFG-Schwerpunktprogramms 1171 in Blaubeuren, 9.–11. Oktober 2006, Forschungen und Berichte zur Vor- und Frühgeschichte in Baden-Württemberg 101 (Stuttgart 2008) 349–366.

Schäuble, 2005
A. Schäuble, Ernährungsrekonstruktion dreier mittelalterlicher Bevölkerungen anhand der Analyse stabiler Isotope und Spurenelemente. PhD thesis, Freie Universität Berlin 2005. Available online: http://www.diss.fu-berlin.de/diss/ (accessed 10. 07. 2011).

Schoeninger, 1979
M. J. Schoeninger, Diet and status at Chalcatzingo: Some empirical and technical aspects of strontium analysis. American Journal of Physical Anthropology 51, 295–310.

Schoeninger, 1985
M. J. Schoeninger, Trophic level effects on 15N/14N and 13C/12C ratios in bone collagen and strontium levels in bone mineral. Journal of Human Evolution 14, 1985, 515–525.

Schoeninger/DeNiro, 1984
M. J. Schoeninger/M. J. DeNiro, Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. Geochimica et Cosmochimica Acta 48, 1984, 625–639.

Schoeninger et al., 1983
M. J. Schoeninger/M. J. DeNiro/H. Tauber, Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. Science 220, 1983, 1481–1383.

Scholz, 1994
F. Scholz, Nomadismus – Mobile Tierhaltung. Formen, Niedergang und Perspektiven einer traditionsreichen Lebens- und Wirtschaftsweise. Geographische Rundschau 46, 1994, 72–78.

Schulz, 2006
D. Schulz, Ontogenetische Trends stabiler Kohlenstoff- und Sauerstoffisotope im menschlichen Zahnschmelz: ist die Bestimmung eines Entwöhnungszeitraumes möglich? Unpublished diploma thesis Ludwig-Maximilians-Universität München 2006.

Schwarcz/Schoeninger, 1991
H. P. Schwarcz/M. J. Schoeninger, Stable isotope analyses in human nutritional ecology. Yearbook of Physical Anthropology 34, 1991, 283–321.

Schwarcz et al., 1991
H. P. Schwarcz/L. Gibbs/M. Knyf, Oxygen isotope analysis as an indicator of place of origin. In: S. Pfeiffer/R. Williamson (Eds.), Snake Hill: An investigation of a military cemetery from the war of 1812 (Toronto 1991) 263–268.

Schweissing, 2004
M. M. Schweissing, Strontium-Isotopenanalyse ($^{87}Sr/^{86}Sr$). Eine archäometrische Applikation zur Klärung anthropologischer und archäologischer Fragestellungen in Bezug auf Migration und Handel. Münchner Geologische Hefte 31 (München 2004).

Schweissing/Grupe, 2000
M. M. Schweissing/G. Grupe, Local or nonlocal? A research of strontium isotope ratios of teeth and bones on skeletal remains with artificial deformed skulls. Anthropologischer Anzeiger 58/1, 2000, 99–103.

Schweissing/Grupe, 2003a
M. M. Schweissing/G. Grupe, Stable strontium isotopes in human teeth and bone: A key to migration events in the late Roman period in Bavaria. Journal of Archaeological Science 30, 2003, 1373–1383.

Schweissing/Grupe, 2003b
M. M. Schweissing/G. Grupe, Tracing migration events in man and cattle by stable strontium isotope analysis of appositionally grown mineralized tissue. International Journal of Osteoarchaeology 13, 2003, 96–103.

Scoryi, 2010
S. Scoryi, Die Skythen. In: J. Leskovar/M-Ch. Zingerle (Eds.), Goldener Horizont. 4000 Jahre in der Ukraine (Weitra 2010) 68–71.

Sealy, 2001
J. Sealy, Body tissue chemistry and palaeodiet. In: D. R. Brothwell/A. M. Pollard (Eds.), Handbook of archaeological science (Chichester 2001) 269–279.

Sealy et al., 1995
J. Sealy/R. Armstrong/C. Schirre, Beyond lifetime averages: Tracing life histories through isotopic analysis of different calcified tissues from archaeological human skeletons. Antiquity 69, 1995, 290–300.

Seghedi et al., 2004
I. Seghedi/H. Downes/A. Szakacs/P. R. D. Mason/M. F. Thirlwall/E. Rosu/Z. Pecskay/E. Marton/C. Panaiotu, Neogene-Quaternary magmatism and geodynamics in the Carpathian-Pannonian region: A synthesis. Lithos 72, 2004, 117–146.

Sharani, 1979
M. N. M. Shahrani, The Kirghiz and Wakhi of Afghanistan: Adaptation to closed frontiers (Seattle, WA 1979).

Sharp, 2007
Z. Sharp, Principles of stable isotope geochemistry (Upper Saddle River, NJ 2007).

Shilov, 1989
V. P. Shilov, The origins of migration and animal husbandry in the steppes of Eastern Europe. In: J. Clutton-Brock (Ed.), The walking larder. Patterns of domestication, pastoralism, and predation. Chiefly proceedings of the 1. World Archaeological Congress held in Sept. 1986 in Southampton, England. One world archaeology 2 (London 1989) 119–126.

Shishlina, 2001a
N. I. Shishlina, The seasonal cycle of grassland use in the Caspian Sea steppe during the Bronze Age: A new approach to an old problem. European Journal of Archaeology 4/2001, 346–365.

Shishlina, 2001b
N. I. Shishlina, Eurasian steppe nomad. In: P. N. Peregrine/M. Ember (Eds.), Encyclopedia of prehistory. Volume 4: Europe (USA 2001) 124–138.

Shishlina, 2003
N. Shishlina, Yamnaya culture pastoral exploitation: A local sequence. In: M. Levine/C. Renfrew/K. Boyle (Eds.), Prehistoric steppe adaptation and the horse (Cambridge 2003) 353–365.

Shishlina, 2004
N. I. Shishlina, North-west Caspian Sea steppe: Environment and migration crossroads of pastoral culture population during the 3rd mill BC. In: E. M. Scott/A. Yu. Alekseev/G. Zaitseva (Eds.), Impact of the environment on human migration in Eurasia. IV Earth and Environmental Sciences 42 (Dordrecht et al. 2004) 91–106.

Shishlina, 2008
N. I. Shishlina, Reconstruction of the Bronze Age of the Caspian steppes: Life styles and life ways of pastoral nomads. BAR International Series 1876 (Oxford 2008).

Shishlina/Hiebert, 1998
N. I. Shishlina/F. T. Hiebert, The steppe and the sown: Interaction between Bronze Age Eurasian nomads and agriculturalists. In: V. H. Mair (Ed.), The Bronze Age and Early Iron Age peoples of eastern Central Asia. Journal of Indo-European Studies Monograph 26 (Washington, D.C. 1998) 222–237.

Shishlina et al., 2000
N. I. Shishlina/A. L. Alexandrovsky/O. A. Chichagova/J. van der Plicht, Radiocarbon chronology of the Kalmykia Catacomb culture of the west Eurasian steppe. Antiquity 74, 2000, 793–799.

Shishlina et al., 2007
N. I. Shishlina/J. van der Plicht/R. E. M. Hedges/E. P. Zazovskaya/V. S. Sevastianov/O. A. Chichagova, The catacomb cultures of the North-west Caspian steppes: 14C chronology, reservoir effect and palaeodiet. Radiocarbon 49 (2), 2007, 713–726.

Shishlina et al., 2008
N. I. Shishlina/E. I. Gak/A. V. Borisov, Nomadic sites of the South Yergueni Hills on the Eurasian steppe: Models of seasonal occupation and production. In: H. Barnard/W. Wendrich (Eds.), The archaeology of mobility. Old World and New World nomadism. Cotsen Advanced Seminars 4 (Los Angeles, CA 2008) 230–249.

Shishlina et al., 2009
N. I. Shishlina/E. P. Zazovskaya/J. van der Plicht/R. E. M. Hedges/V. S. Sevastyanov/O. A. Chichagova, Paleoecology, subsistence, and ^{14}C chronology of the Eurasian Caspian steppe Bronze Age. Radiocarbon 51/2, 2009, 481–499.

Shishlina et al., 2012
N. Shishlina/V. Sevastyanov/R. E. M. Hedges, Isotope ratio study of Bronze Age samples from the Eurasian Caspian steppes. In: E. Kaiser/J. Burger/W. Schier (Eds.), Population dynamics in prehistory and early history. New approaches using stable isotopes and genetics. Topoi. Berlin Studies of the Ancient World 5 (Berlin 2012) 177–197.

Shnirelman et al., 1996
V. A. Shnirelman, S. L. Olsen, P. Rice, Hooves across the steppe. The Kazak life-style. In: S. L. Olsen (Ed.), Horses through time (Boulder, CO 2006) 129–152.

Sjögren et al., 2009
K.-G. Sjögren/T. D. Price/T. Ahlström, Megaliths and mobility in south-western Sweden. Investigating relationships between a local society and its neighbours using strontium isotopes. Journal of Anthropological Archaeology 28, 2009, 85–101.

Slovak et al., 2009
N. M. Slovak/A. Paytan/B. A. Wiegand, Reconstructing middle horizon mobility patterns on the coast of Peru through strontium isotope analysis. Journal of Archaeological Science 36, 2009, 157–165.

Ślusarska, 2006
K. Ślusarska, Funeral rites of the Catacomb community: 2800–1900 BC. Ritual, thanatology and geographical origins. Baltic-Pontic studies 13 (Poznań 2006).

Sponheimer/Lee-Thorp, 1999
M. Sponheimer/J. A. Lee-Thorp, Oxygen isotopes in enamel carbonate and their ecological significance. Journal of Archaeological Science 26, 1999, 723–728.

Stasevič, 2013
I. Stasevič, Die sozio-ökonomischen Modelle der Viehzüchter Kasachstans. Ein historischer Abriss. In: Th. Stöllner/Z. Samasev (Eds.), Unbekanntes Kasachstan – Archäologie im Herzen Asiens. Katalog zur Ausstellung des Deutschen Bergbau-Museums Bochum vom 26. Januar bis zum 30. Juni 2013 (Bochum 2013) 19–25.

Stephan, 1999
E. Stephan, Sauerstoffisotopenverhältnisse im Knochengewebe großer terrestrischer Säugetiere. Klimaproxies für das Quartär in Mittel- und Westeuropa. Tübinger Geowissenschaftliche Arbeiten E 6/99 (Tübingen 1999).

Stephan et al., 2012
E. Stephan/C. Knipper/K. Schatz/T. D. Price/E. Hegner, Strontium isotopes in faunal remains: Evidence of the strategies for land use at the Iron Age site Eberdingen-Hochdorf (Baden-Württemberg, Germany). In: E. Kaiser/J. Burger/W. Schier (Eds.), Population dynamics in prehistory and early history. New approaches using stable isotopes and genetics. Topoi. Berlin Studies of the Ancient World 5 (Berlin 2012) 265–286.

Steuer, 2001
H. Steuer, Stichwort: Mobilität. In: H. Beck/D. Geuenich/H. Steuer (Eds.), Reallexikon der germanischen Altertumskunde. Bd. 20: Metuonis-Naturwissenschaftliche Methoden in der Archäologie (Berlin 2001) 118–123.

Stevens et al., 2010
R. E. Stevens/R. M. Jacobi/T. F. G. Higham, Reassessing the diet of Upper Palaeolithic humans from Gough's Cave and Sun Hole, Cheddar Gorge, Somerset, UK. Journal of Archaeological Science 37, 2010, 52–61.

Stuart-Williams/Schwarcz, 1997
H. Le Q. Stuart-Williams/H. P. Schwarcz, Oxygen isotopic determination of climatic variation using phosphate from beaver bone, tooth enamel, and dentine. Geochimica et Cosmochimica Acta 61, 1997, 2539–2550.

Sühs, 2007
B. Sühs, Studien zu Tierbestattungen im prähistorischen Mitteleuropa. Unpublished M.A. thesis, Julius-Maximilians-Universität Würzburg 2007.

Szmyt, 1999
M. Szmyt, Between west and east: People of the Globular Amphora culture in eastern Europe: 2950–2350 BC. Baltic-Pontic Studies 8 (Poznán 1999).

Szmyt, 2002
M. Szmyt, Kugelamphoren-Gemeinschaften in Mittel- und Osteuropa: Siedlungsstrukturen und soziale Fragen. In: J. Müller (Ed.), Vom Endneolithikum zur Frühbronzezeit: Muster sozialen Wandels? (Tagung Bamberg 14.–16. Juni 2001) (Bonn 2002) 195–233.

Szmyt, 2003
M. Szmyt, Verbreitung und Kontakte der Kugelamphorenkultur: Ein Blick auf die polykulturellen Peripherien. Germania 81, 2003, 401–441.

Szmyt, 2006
M. Szmyt, Dead animals and living society. Available online: www.jungsteinsite.de (accessed 15. 12. 2006).

Szmyt, 2008
M. Szmyt, Baden patterns in the milieu of the Globular Amphorae: Transformation, incorporation and long continuity. A case study from the Kujavian region, Polish Lowlands. In: M. Furholt/M. Szmyt/A. Zastawny (Eds.), The Baden complex and the outside world. Proceedings of the 12th annual meeting of the EAA in Cracow 19–24th September 2006 (Bonn 2008) 217–232.

Tafuri et al., 2006
M. A. Tafuri/R. A. Bentley/G. Manzi/S. di Lernia, Mobility and kinship in the prehistoric Sahara: Strontium isotope analysis of Holocene human skeletons from the Acacus Mts. (southwestern Libya). Journal of Anthropological Archaeology 25, 2006, 390–402.

Telegin, 1987
D. Y. Telegin, On the Yamna Culture. Current Anthropology 28, 1987, 357–358.

Telegin, 2002
D. Ya. Telegin, A discussion of some of the problems arising from the study of Neolithic and Eneolithic cultures in the Azov Black Sea Region. In: K. Boyle/C. Renfrew/M. Levine (Eds.), Ancient interactions: East and west in Eurasia (Cambridge 2002) 25–47.

Telegin et al., 2003
D. Y. Telegin/S. Z. Pustovalov/N. N. Kovaliukh, Relative and absolute chronology of Yamnaya and Catacomb monuments. The issue of co-existence. In: A. Kośko/

V. I. Klochko (Eds.), The foundations of radiocarbon chronology of cultures between the Vistula and Dnieper: 4000–1000 BC. Baltic-Pontic Studies 12, 2003, 132–184.

Thirlwall, 1991
M. F. Thirlwall, Long-term reproducibility of multicollector Sr and Nd isotope ratio analysis. Chemical Geology 94, 1991, 84–104.

Tilly, 1978
Ch. Tilly, Migration in modern European history. In: W. McNeill/R. Adams (Eds.), Human migration. Patterns, implications, policies (Bloomington, IN 1978), 48–74.

Todorova, 1991
H. Todorova, Die Kupferzeit Bulgariens. In: J. Lichardus (Ed.), Die Kupferzeit als historische Epoche. Saarbrücker Beiträge zur Altertumskunde 55. Teil 1 (Bonn 1991) 89–93.

Towers et al., 2010
J. Towers/J. Montgomery/J. Evans/M. Jay/M. Parker Pearson, An investigation of the origins of cattle and aurochs deposited in the Early Bronze Age barrows at Gayhurst and Irthlingborough. Journal of Archaeological Science 37, 2010, 508–515.

Trickett et al., 2003
M. A. Trickett/P. Budd/J. Montgomery/J. Evans, An assessment of solubility profiling as a decontamination procedure for the 87Sr/86Sr analysis of archaeological human skeletal tissue. Applied Geochemistry 18, 2003, 653–658.

Trifonov et al., 2012
V. A. Trifonov/G. I. Zaitseva/J. van der Plicht/N. D. Burova/E. S. Bogomolov/A. A. Sementsov/O. V. Lokhova, The dolmen Kolikho, Western Caucasus: Isotopic investigation of funeral practice and human mobility. Radiocarbon 54, 2012, 761–769.

Trunkó, 1969
L. Trunkó, Geologie von Ungarn. Beiträge zur regionalen Geologie der Erde (Berlin/Stuttgart 1969).

Trunkó, 1996
L. Trunkó, Geology of Hungary (Berlin 1996).

Tütken, 2003
Th. Tütken, Die Bedeutung der Knochenfrühdiagenese für die Erhaltungsfähigkeit in vivo erworbener Element- und Isotopenzusammensetzungen in fossilen Knochen. PhD thesis, Eberhard-Karls Universität Tübingen. Available online: http://w210.ub-uni tuebingen.de/dbt/volltexte/2003/962/ (accessed 01. 07. 2010).

Tütken, 2010
Th. Tütken, Die Isotopenanalyse fossiler Skelettreste – Bestimmung der Herkunft und Mobilität von Menschen und Tieren. Tagungsband des 2. Mitteldeutschen Archäologentages in Halle (Saale): Anthropologie, Isotopie und DNA – biographische Annäherung an namenlose vorgeschichtliche Skelette? Tagungen des Landesmuseums für Vorgeschichte Halle 3 (Halle (Saale) 2010) 33–51.

Tütken et al., 2004
Th. Tütken/T. W. Vennemann/H.-U. Pfretzschner, Analyse stabiler und radiogener Isotope in archäologischem Skelettmaterial: Herkunftsbestimmung des karolingischen Maultiers von Frankenthal und Vergleich mit spätpleistozänen Großsäugerknochen aus den Rheinablagerungen. Prähistorische Zeitschrift 79/1, 2004, 89–110.

Tütken et al., 2008
Th. Tütken/C. Knipper/K. W. Alt, Mobilität und Migration im archäologischen Kontext: Informationspotential von Multi-Element-Isotopenanalysen (Sr, Pb, O). In: J. Bemmann/M. Schmauder (Eds.), Langobarden – Awaren – Slawen. Kulturwandel in Mitteleuropa. Akten der Internationalen Tagung in Bonn vom 25. bis 28. Februar 2008, Kolloquien zur Vor- und Frühgeschichte 11 (Bonn 2008) 13–42.

Turner et al., 2009
B. L. Turner/G. D. Kamenov/J. D. Kingston/G. J. Armelagos, Insights into immigration and social class at Machu Picchu, Peru, based on oxygen, strontium, and lead isotopic analysis. Journal of Archaeological Science 36, 2009, 317–332.

Újvári et al., 2010
G. Újvári/F. C. Ramos/C. Dimond/J. Kovács/G. Varga/A. Varga, On possible sources of loess deposits in the Carpathian Basin: an isotopic approach. Geophysical Research Abstracts 12, EGU 2010–3881–1, 2010, 3881.

Vainshtein, 1980
S. I. Vainshtein, Nomads of South Siberia (Cambridge 1980).

Valentine et al., 2008
B. Valentine/G. D. Kamenov/J. Krigbaum, Reconstructing Neolithic groups in Sarawak, Malaysia through lead and strontium isotope analysis. Journal of Archaeological Science 35, 2008, 1463–1473.

Viner et al., 2010
S. Viner/J. Evans/U. Albarella/M. Parker Pearson, Cattle mobility in prehistoric Britain: strontium isotope analysis of cattle teeth from Durrington Walls (Wiltshire, Britain). Journal of Archaeological Science 37, 2010, 2812–2820.

Vinogradov, 1996
Ju. A. Vinogradov, Natural-climatic conditions as a factor in the development of the Bosporus in the Scythian epoch. Vestnik drevnej istorii 3, 1996, 77–88.

Voerkelius et al., 2010
S. Voerkelius/G. D. Lorenz/S. Rummel/C. R. Quétel/G. Heiss/M. Baxter/C. Brach-Papa/P. Deters-Itzelberger/S. Hoelzl/J. Hoogewerff/E. Ponzevera/M. van Bocxstaele/H. Ueckermann, Strontium isotopic signatures of natural mineral waters, the reference to a simple geological map and its potential for authentication of food. Food Chemistry 118, 2010, 933–940.

Vogel/van der Merwe, 1977
J. C. Vogel/N. J. van der Merwe, Isotopic evidence for early maize cultivation in New York State. American Antiquity 42, 1977, 238–242.

Vohberger, 2011
M. Vohberger, Lokal oder Eingewandert? Interpretationsmöglichkeiten und Grenzen lokaler Strontium- und Sauerstoffisotopensignaturen am Beispiel einer Altgrabung in Wenigumstadt. PhD thesis Ludwig-Maximilians-Universität München 2011. Available online: edoc.ub.uni-muenchen.de/12741/1/Vohberger_Marina.pdf (accessed 10. 01. 2012)

Vollmann, 2009
D. Vollmann, Der Mako-Kosihy-Caka-Komplex und die früheste Nagyrév-Kultur an Donau und Theiß. In: V. Becker/M. Thomas/A. Wolf-Schuler (Eds.), Zeiten – Kulturen – Systeme. Gedenkschrift für Jan Lichardus (Langenweißbach 2009) 271–287.

Wang/Cerling 1994
Y. Wang/T. E. Cerling, A model of fossil tooth and bone diagenesis: Implications for paleodiet reconstruction from stable isotopes, Palaeogeography, Palaeoclimatology, Palaeoecology 107, 1994, 281–289.

Warmuth et al., 2011
V. Warmuth/A. Eriksson/M.A. Bower/J. Cañon/G. Cothran/O. Distl/M.-L. Glowatzki-Mullis/H. Hunt/C. Luís/M. Do Mar Oom/I. Tupac Yupanqui/T. Ząbek/A. Manica, European domestic horses originated in two Holocene refugia. PLoS One 6(3), 2011. Doi:10.1371/journal.pone.0018194.

Weber, 1964
V. Weber, Die Kugelamphorenkultur in Sachsen. Arbeits- und Forschungsberichte zur sächsischen Bodendenkmalpflege 13, 1964, 73–192.

Weber et al., 2011
A. W. Weber/D. White/V. I. Bazaliiskii/O. I. Goriunova/N. A. Savel'ev/M. A. Katzenberg, Hunter-gatherer foraging ranges, migrations, and travel in the middle Holocene Baikal region of Siberia: Insights from carbon and nitrogen stable isotope signatures. Journal of Anthropological Archaeology 30, 2011, 523–548.

Weiß et al., 2011
J. Weiß/W. Papst/S. Granz, Tierproduktion (Stuttgart 2011).

Wendrich/Barnard, 2008
W. Wendrich/H. Barnard, The archaeology of mobility: Definitions and research approaches. In: H. Barnard/W. Wendrich (Eds.), The archaeology of mobility. Old World and New World nomadism. Cotsen Advanced Seminars 4 (Los Angeles, CA 2008) 1–21.

Weninger et al., 2009
B. Weninger/L. Clare/E. J. Rohling/O. Bar-Yosef/U. Bohner/M. Budja/M. Bundschuh/A. Feurdean/H.-G. Gebel/O. Joris/J. Linstadter/P. Mayewski/T. Muhlenbruch/A. Reingruber/G. Rollefson/D. Schyle/L. Thissen/H. Todorova/Ch. Zielhofer, The impact of rapid climate change on prehistoric societies during the Holocene in the Eastern Mediterranean. Documenta Praehistorica 36, 2009, 7–59.

Wentz/de Grummond, 2009
R. K. Wentz/N. T. de Grummond, Life on a horseback: Palaeopathology of two Scythian skeletons from Alexandropol, Ukraine. International Journal of Osteoarchaeology 19, 2009, 107–115.

White et al., 1998
Ch. D. White/M. W. Spence/H. Le Q. Stuart-Williams/H. P. Schwarcz, Oxygen isotopes and the identification of geographical origins: The Valley of Oaxaca versus the Valley of Mexico. Journal of Archaeological Science 25, 1998, 643–655.

White et al., 2000
C. D. White/F. J. Longstaffe/M. W. Spence/K. R. Law, Teotihuacan state representation at Kaminaljuyú: Evidence from oxygen isotopes. Journal of Anthropological Research 56, 2000, 535–558.

White et al., 2001
C. D. White/F. J. Longstaffe/K. R. Law, Revisiting the Teotihuacan connection at Altun Ha: Oxygen isotope analysis of tomb f-8/1. Ancient Mesoamerica 12, 2001, 65–72.

White et al., 2002
C. D. White/F. J. Longstaffe/M. W. Spence/H. Le Q. Stuart-Williams/K. R. Law, Geographic identities of the sacrificial victims from the Feathered Serpent Pyramid, Teotihuacan: Implications for the nature of state power. Latin American Antiquity 13, 2002, 371–393.

White et al., 2004a
C. D. White/M. W. Spence/F. J. Longstaffe/K. R. Law, Demography and ethnic continuity in the Tlailotlacan enclave of Teotihuacan: The evidence from stable oxygen isotopes. Journal of Anthropological Archaeology 23, 2004, 385–403.

White et al., 2004b
C. D. White/F. J. Longstaffe/K. R. Law, Exploring the effects of environmental, physiology and diet on oxygen isotope ratios in ancient Nubian bones and teeth. Journal of Archaeological Science 31, 2004, 233–250.

White et al., 2007
C. D. White/T. D. Price/F. J. Longstaffe, Residential histories of the human sacrifices at the Moon Pyramid, Teotihuacan. Evidence from oxygen and strontium isotopes. Ancient Mesoamerica 18, 2007, 159–172.

White/Folkens, 2005
T. D. White/P. A. Folkens, The human bone manual (Amsterdam 2005).

Whittle et al., 2002
A. Whittle/L. Bartosiewicz/D. Borić/P. Pettitt/M. Richards, In the beginning: New radiocarbon dates for the early neolithic in northern Serbia and Southeast Hungary. Antaeus 25, 2002, 72–117.

Wojchiechowski, 1998
W. Wojchiechovski, Die Kugelamphorenkultur. In: J. Preuß (Ed.), Das Neolithikum in Mitteleuropa. Kulturen – Wirtschaft – Umwelt von 6. bis 3. Jahrtausend v. u. Z. Übersichten zum Stand der Forschung. Teil A: Das Neolithikum in Mitteleuropa (Weissbach 1998) 401–407.

Wright, 2005
L. E. Wright, Identifying immigrants to Tikal, Guatemala: Defining local variability in strontium isotope ratios of human tooth enamel. Journal of Archaeological Science 32, 2005, 555–566.

Wright/Schwarcz, 1998
L. E. Wright/H. P. Schwarcz, Stable carbon and oxygen isotopes in human tooth enamel: identifying breastfeeding and weaning in prehistory. American Journal of Physical Anthropology 106, 1998, 1–18.

Wright et al., 2010
L. E. Wright/J. A. Valdés/J. H. Burton/T. D. Price/H. P. Schwarcz, The children of Kaminaljuyu: Isotopic insight into diet and long distance interaction in Mesoamerica. Journal of Anthropological Archaeology 29, 2010, 155–178.

Zalai-Gaál, 1998
I. Zalai-Gaál, Das Rindergrab von Endröd 130. Neue Angaben zum Tierkult der mitteleuropäischen Kupferzeit. In: P. Anreiter/L. Bartosiewicz/E. Jerem/W. Meid (Eds.), Man and the Animal World. Studies in Archaeozoology, Archaeology, Anthropology and Palaeolinguistics in memoriam Sándor Bökönyi (Budapest 1998) 545–568.

Zazzo et al., 2002
A. Zazzo/A. Mariotti/C. Lecuyer/E. Heintz, Intra-tooth isotope variations in late Miocene bovid enamel from Afghanistan: palaeobiological, taphonomic and climatic implications. Palaeogeography, Palaeoclimatology, Palaeoecology 186, 2002, 145–161.

Appendices

Appendix A
I Sites
II Samples

Appendix B
Data $^{87}Sr/^{86}Sr$ analysis

Appendix C
Data $\delta^{18}O$ analysis

Appendix D
Data $\delta^{13}C$ and $\delta^{15}N$ analysis

Introduction to the Appendices

In Appendix A I the sample sites are introduced. They are arranged in the first instance chronologically then by location, and are listed alphabetically within each section. The sections for each site contain information regarding location, the archaeological and geological context, sample selection, and include references. Coordinates are expressed as decimal degrees. References are abbreviated when mentioned in the text body, whereas additional references are given in full.

Appendix A II provides information on the individuals selected for isotopic analysis. Each sample is provided with the archaeological and anthropological context and the results of $^{87}Sr/^{86}Sr$, $\delta^{18}O$, $\delta^{15}N$ and $\delta^{13}C$ analyses. Sample sites are arranged chronologically, and are listed alphabetically within each section.

Additional results obtained from $^{87}Sr/^{86}Sr$ analysis are presented in Appendix B, firstly in chronological and secondly in alphabetic order.

The results obtained from $\delta^{18}O$ analysis are presented in Appendix C, again firstly in chronological and secondly in alphabetic order. Additional to the results obtained from the $\delta^{18}O$ analysis in tooth enamel carbonate, the tables include a breakdown of the mathematical conversions from $\delta^{18}O_{carbonate}$ (vs. V-PDB) to $\delta^{18}O_{water}$ (vs. V-SMOW).

Appendix D provides information obtained from $\delta^{13}C$ and $\delta^{15}N$ analysis.

Appendix A

I Sites

Eneolithic and Bronze Age

Bulgaria
1 Benkovski
2 Boyanovo
3 Ovchartsi
4 Smyadovo

Hungary
5 Sárrétudvari-Őrhalom
6 Kétegyháza-Kétegyházi tanyák
7 Balmazújváros-Árkusmajor-Kettőshalom
8 Debrecen-Basahalom
9 Debrecen-Dunahalom
10 Dévaványa-Barcéhalom
11 Dévaványa-Csordajárás
12 Püspokladány-Kincsesdomb
13 Sárrétudvari-Balázshalom

Ukraine
14 Kirovograd
15 Nevskoe
16 Peshtchanka
17 Shakhta Stepnaya
18 Vinogradnoe

Russia
19 Kalinovka I
20 Nikolaevka III
21 Olennii
22 Podlesnyi
23 Politotdel'skoe
24 Sukhaya Termista II

Iron Age

Ukraine
25 Alexandropol'
26 Babina Mogila
27 Drana Kokhta
28 Ordzhonikidze
29 Zolotaya Balka

Kazakhstan
30 Berel'

Case Study Chapter 5: Globular Amphora Culture

Germany
31 Zauschwitz

Eneolithic and Bronze Age

Bulgaria

1 Benkovski

District of Nova Zagora.
Coordinates: 42.40901° N, 25.9018° E.

Archaeology
Group of 5 kurgans, 2 excavated.
Excavations in 2008 and 2009 by St. Alexandrov and P. Karailiev:

- Kurgan 1: diam. 20 m, H 0.4 m, 3 graves (Early Bronze Age).
- Kurgan 2: diam. 16 m, H 0.3 m, 9 graves (Early Bronze Age).

Geology
Located on a plain in an area of homogeneous Cenozoic sediments.
< 20 km from Mesozoic rocks (to the north), Mesozoic geology and Palaeozoic plutonites and metamorphic rocks (to the east).

Samples

- Kurgan 1: graves 2, 3.
- Kurgan 2: graves 1, 2, 3, 4, 6, 7, 9.

$^{87}Sr/^{86}Sr$ reference material
Appendix A I Table 1 (p. 343).

References
Excavation report (unpublished):
St. Aleksandrov/P. Karailiev, Nadgrobni mogili, Obekt N 11, Lot 2, AM 'Trakia', zemlishte na s. Benkovski, obshtina Stara Zagora, 2009 g.

St. Aleksandrov/P. Karailiev, Spasitelni arkheologicheski prouchvania na obekt No. 11, po AM 'Trakia', LOT 2, s. Benkovski, obshtina Stara Zagora – str. 113. AOR prez 2009 (Sofia 2010).

2 Boyanovo

District of Yambol.
Coordinates: 42.26361° N, 26.61334° E.

Archaeology
Group of 6 kurgans, excavations in 2007 and 2008 by D. Agre:

- Lozyanska Mogila: overlooking the plain, diam. > 30 m, H 5.5 m, 22 graves (9 Early Bronze Age, 12 Middle Bronze Age, 1 Iron Age), 5 graves connected to Yamnaya culture.

Geology
Situated in a hilly region near the river Tundzha. Varying geology: Cenozoic sediments in the river plain, Palaeozoic to Mesozoic metamorphic bedrock.
<10 km from Mesozoic geology (to the northeast), and Palaeozoic metamorphic bedrock and Mesozoic plutonites (to the southeast).

Samples

- Lozyanska Mogila: graves 4, 5, 6, 14 skeletons 1 and 2.

$^{87}Sr/^{86}Sr$ reference material
Appendix A I Table 2 (p. 343).

References
Unpublished.
Pers. comm. D. Agre.

3 Ovchartsi

District of Radnevo.
Coordinates: 42.19775° N, 26.04652° E.

Archaeology
Excavations in 1986 by H. Buyukliev and P. Kalchev and rescue excavations in 2002 by I. Panayotov and St. Alexandrov:

- 'Kurgan in the Vineyards': diam. 10 m, H 1 m, single kurgan situated on a plateau in a valley, 7 graves (Early Bronze Age, connected to Yamnaya).
- 'The Big Tumulus': diam. ~ 45 m, H ?, single kurgan on a hill, 15 graves (Early Bronze Age, connected to Yamnaya).

Geology
Sited on Cenozoic sediments in a geologically varied region.
< 10 km from Mesozoic plutonites and Palaeozoic-Mesozoic metamorphic bedrock (to the east); < 20 km from partly metamorphosed Palaeozoic rocks (to the south).

Samples
- 'Kurgan in the Vineyards': grave 3.
- 'The Big Tumulus': graves 1, 2, 9, 15.

$^{87}Sr/^{86}Sr$ reference material
Appendix A I Table 3 (p. 343).

References
I. Panayotov/St. Alexandrov, Spasitelni arheologicheski prouchvaniya na nadgrobna mogila v zemlishteto na selo Ovcharci, obshtina Radnevo. AOR za 2004 godina, 2005, 79–80.

St. Alexandrov/T. Hristova, Spasitelni arheologicheski razkopki na Mogilata v lozjata v zemlishteto na selo Ovcharci, obshtina Radnevo. AOR za 2008 godina, 2009, 130–132.

4 Smyadovo

Districtof Shumen.
Coordinates: 43.05255° N, 26.99511° E.

Archaeology
Excavations in 2006 and 2007 by St. Chohadzhiev and S. Venelinova:
- Flat grave cemetery: 23 graves (18 Eneolithic, 5 Early Bronze Age).

Geology
Situated in a hilly region at the south-eastern edge of the Danubian Plain and the northern foothills of the eastern Balkan Mountains; an area of Cretaceous bedrock;
< 20 km from Triassic-Jurassic outcrops (to the south) and Cenozoic sediments (to the east and south).

Samples
- Graves 6, 10, 11, 13, 15, 16, 22, 26.

$^{87}Sr/^{86}Sr$ reference material
Appendix A I Table 4 (p. 344).

References
St. Chokhadzhiev/S. Venelinova, Novootkrit halkoliten nekrolol kraj Smyadovo. In: M. Gyurova (ed.), Praistoricheski prouchvaniya v Bulgaria: novite predizvikatelstva, 2008.

St. Chokhadzhiev/S. Venelinova, Arkheologicheski prouchvanya na khalkolitniya nekropol v m. Gorlomova koriya krai grad Smyadovo. AOR za 2006 godina, 2007, 65–70.

St. Chokhadzhiev/S. Venelinova, Arkheologichesko prouchvane na praistoricheski nekropol v m. Gorlomova koriya krai Smyadovo. AOR za 2007 godina, 2008, 100–101.

Hungary

5 Sárrétudvari-Őrhalom

Hajdú-Bihar County.
Coordinates: 47.24565° N, 21.18783° E (village of Sárrétudvari).

Archaeology
Single burial mound.
Rescue excavations in 1986, 1987, 1988, 1992, 1998 by I. M. Nepper and J. Dani:

- 7 graves (Eneolithic and Early Bronze Age), burials of the Hungarian Conquest Period.

Geology
Wide-ranging homogeneous geology with Cenozoic sediments.
< 100 km (in south-easterly direction) from the foothills of the Precambrian to Mesozoic Carpathian Mountains (Apuseni Mountains).

Samples

- Graves 4, 7, 7a, 8, 9, 10, 11, 12.

$^{87}Sr/^{86}Sr$ reference material
Appendix A I Table 5 (p. 344).

References
Dani/Nepper, 2006.

Kalicz, 1998.

D. Vollmann, Studien zum Übergang von der Kupferzeit zur frühen Bronzezeit im östlichen Mitteleuropa. Saarbrücker Beiträge zur Altertumskunde 77 (Bonn 2005) 82–84.

6 Kétegyháza-Kétegyházi tanyák

Békés County.
Coordinates: 46.54162° N, 21.18336° E (village of Kétegyháza).

Archaeology
Site with a kurgan field, traces of early Baden settlement, settlement of the Bodrogkeresztúr culture, an Early Iron Age grave, Sarmatian burials, and a settlement of the Late Middle Ages. Excavations in 1966–1968 by Gy. Gazdapusztai:

- Kurgan 3: built together with kurgans 3a and 3b on a natural uplift, estimated H 7.08 m, possibly 3 phases, 1st kurgan built over grave 7, graves 1–3 dating to the Sarmatian period, graves 4–7 Yamnaya.
- Kurgan 5a: forms one group together with kurgans 5, 5b, and 6, H: 0.6 m.
- Kurgan 6: ~ H 1.5 m, 2 Yamnaya burials, numerous ceramics and remains of hearths on original surface.

Geology
Wide-ranging homogeneous geology with Cenozoic sediments. > 100 km (in easterly and south-easterly direction) from the foothills of the Precambrian to Mesozoic Carpathian Mountains (Apuseni Mountains).

Samples

- Kurgan 3: grave 7.
- Kurgan 5a: grave 1.
- Kurgan 6: graves 1, 3.

$^{87}Sr/^{86}Sr$ reference material
Appendix A I Table 6 (p. 344).

References
Gy. Gazdapusztai, Chronologische Fragen in der Alfölder Gruppe der Kurgan-Kultur. Móra Ferenc Múz. Évk. 1966/67, 93, 96.

Ecsedy, 1979, 20–33; fig. 7–22; pl. 4–10; 11, 1–4; 12–16.

7 Balmazújváros-Árkusmajor-Kettőshalom

Hajdú-Bihar County.
Coordinates: 47.60801° N, 21.34163° E (village of Balmazújváros).

Archaeology
Kurgan situated by the Arkus stream. Excavations in 1964 by Gy.Gazdapusztai. Major part of the kurgan levelled.

Geology
Wide-ranging homogeneous geology with Cenozoic sediments. < 150 km (in south-easterly direction) from the foothills of the Precambrian to Mesozoic Carpathian Mountains (Apuseni Mountains).

Samples
- Grave 1.

$^{87}Sr/^{86}Sr$ reference material
Dentine sample: grave 1.

References
Ecsedy, 1979, 19–20; 19 fig. 5; 20 fig. 6.

Gy. Gazdapusztai, Zur Frage der Verbreitung der sogenannten "Ockergräberkultur" in Ungarn. Móra Ferenc Múz. Évk.1963/65, 35.

8 Debrecen-Basahalom

Hajdú-Bihar County.
Coordinates: 47.52532° N, 21.63174° E (city of Debrecen).

Archaeology
Excavations in 1907 by L. Zoltai:
- Single burial mound: diam. 60 m, H 6.5 m.

Geology
Wide-ranging homogeneous geology with Cenozoic sediments. ~ 100 km (in south-easterly direction) from the foothills of the Precambrian to Mesozoic Carpathian Mountains (Apuseni Mountains).

Samples
- Grave 1.

$^{87}Sr/^{86}Sr$ reference material
None.

References
Ecsedy, 1979, 17.

Kalicz, 1968, 21.

L. Zoltai, Jelentés a Debreceni városi múzeum 1906. Évi régészeti ásatásairól. Múz. és Könyvtári Ért. 1907, 26–28.

9 Debrecen-Dunahalom (Orhat)

Hajdú-Bihar County.
Coordinates: 47.52532° N, 21.63174° E (city of Debrecen).

Archaeology
Kurgan excavated in 1923 by L. Zoltai.

Geology
Wide-ranging homogeneous geology with Cenozoic sediments. ~ 100 km (in south-easterly direction) from the foothills of the Precambrian to Mesozoic Carpathian Mountains (Apuseni Mountains).

Samples
- Grave 1.

$^{87}Sr/^{86}Sr$ reference material
None.

References
Ecsedy, 1979, 16.

Kalicz, 1968, 20.

L. Zoltai, A sárándi testhalmok. DM Jelentések 1923, 12.

10 Dévaványa-Barcéhalom

Békés County.
Coordinates: 47.03082° N, 20.95367° E (village of Dévaványa).

Archaeology
Excavations restricted to a small area of the site:
- Central burial unopened.
- Kurgan: diam. ?, H 2 m, 2 graves, several building stages.

Geology
Wide-ranging homogeneous geology with Cenozoic sediments. < 150 km (in south-easterly direction) from the foothills of the Precambrian to Mesozoic Carpathian Mountains (Apuseni Mountains).

Samples
- Grave 1.

$^{87}Sr/^{86}Sr$ reference material
Dentine sample: grave 1.

References
I. Ecsedy, Eine neue Hügelbestattung der „Grubengrab"-Kultur (Kupferzeit-Frühbronzezeit) in Dévaványa, Mitt. Arch. Inst. 2, 1971, 45–50, pl. 20–21.

I. Ecsedy, Dévaványa, Barcéhalom (Kom. Békés, Kr. Szeghalom). Mitt. Arch. Inst. Ungar. Akad. 2, 1969 (1971) 13.

Ecsedy, 1979, 17–18, fig. 3, 1–3.

11 Dévaványa-Csordajárás

Békés County.
Coordinates: 47.03082° N, 20.95367° E (village of Dévaványa).

Archaeology
Rescue excavations:
- Kurgan: 3 graves, probably arranged before erection of the burial mound.

Geology
Wide-ranging homogeneous geology with Cenozoic sediments. < 150 km (in south-easterly direction) from the foothills of the Precambrian to Mesozoic Carpathian Mountains (Apuseni Mountains).

Samples
- Graves 2, 3.

$^{87}Sr/^{86}Sr$ reference material
Dentine sample: grave 3.

References
Ecsedy, 1979, 33–34, fig. 24–26, pl. 11, 5–6, 17.

12 Püspokladány-Kincsesdomb

Hajdú-Bihar County.
Coordinates: 47.31509° N, 21.11744° E (village of Püspokladány).

Archaeology
Rescue excavation in 1969 by I. M. Nepper:
- Kurgan erected in several stages.

- Primary burial grave 3 (Yamnaya) not sampled, grave 1 (sampled) in highest part of kurgan, later graves.

Geology
Wide-ranging homogeneous geology with Cenozoic sediments. < 150 km (in south-easterly direction) from the foothills of the Precambrian to Mesozoic Carpathian Mountains (Apuseni Mountains).

Samples
- Grave 1.

$^{87}Sr/^{86}Sr$ reference material
None.

References
Ecsedy, 1979, 19.

13 Sárrétudvari-Balázshalom

Hajdú-Bihar County.
Coordinates: 47.24565° N, 21.18783° E (village of Sárrétudvari).

Archaeology
Belongs to the group of kurgans surrounding Debrecen that were excavated between 1907 and 1927 by L. Zoltai:
- Kurgan: diam. 60 m, H 7–8 m.

Geology
Wide-ranging homogeneous geology with Cenozoic sediments. ~ 100 km (in south-easterly direction) from the foothills of the Precambrian to Mesozoic Carpathian Mountains (Apuseni Mountains).

Samples
- 1 individual.

$^{87}Sr/^{86}Sr$ reference material
Dentine sample: HU 20.

References
Ecsedy, 1979, 15–16.

Kalicz, 1968, 20.

L. Zoltai, Jelentések halmok megásatásáról. Jel. Debrecen 1910, 36.

Ukraine

14 Kirovograd

Province and region Kirovograd.
Coordinates: 48.51422° N, 32.19543° E.

Archaeology
Kurgan 'Sugokleya' situated at the periphery of the city of Kirovograd. Excavations in 2004 by Y. V. Boltrik (Institute of Archaeology of the Ukrainian Academy of Sciences):
- Kurgan: diam. ~ 50 m, preserved H ~ 5.6 m, 26 graves (11 Yamnaya, 1 Catacomb culture, 14 Babino culture).
- 3 Early Bronze Age stratigraphic phases: 1st phase including graves 22, 14, 8, 20, 5, 2nd phase including graves 10, 24, 3rd phase including graves 26, 11, 12, 16.

Geology
Mixed geology of Cenozoic sediments together with Proterozoic plutonites. The local geology is characterized by Cenozoic sediments with irregular outcrops of Proterozoic plutonite (< 10 km), in close proximity to the valley of the river Ingul with Proterozoic metamorphic outcrops along the river valley.

Samples
- Graves 5, 10 child, 10 adult, 13, 14, 16, 20, 24.

$^{87}Sr/^{86}Sr$ reference material
Appendix A I Table 7 (p. 345).

References
Nikolova/Kaiser, 2009.

15 Nevskoe

Province Lugansk, Kremenskii region.
Coordinates: 49.1701° N, 37.97648° E (village of Nevskoe).

Archaeology
Group of kurgans, excavated in 1998 (no further information).

Geology
Located on Cretaceous geology, in an area of both Cretaceous bedrock and Cenozoic sediments.
< 20 km from Triassic, Jurassic and Cretaceous metamorphic rocks (to the south), < 50 km from Palaeozoic bedrock (to the south).

Samples
- Kurgan 2 grave 10.
- Kurgan 3 grave 3.
- Kurgan 4 graves 2, 3.
- Kurgan 5 grave 9.

$^{87}Sr/^{86}Sr$ reference material
Dentine samples: kurgan 2 grave 10, kurgan 3 grave 3, kurgan 4 grave 2.

References
Unpublished.
Pers. notes E. Kaiser.

16 Peshtchanka

Province Dniepropetrovsk, Novomoskovsk region.
Coordinates: 48.59994° N, 35.31237° E (village of Peshtchanka).

Archaeology
Group of kurgans. Excavations by D. Teslenko in 2007:
- Kurgan 1: part of kurgan group 2, 15 graves (5 Eneolithic, 6 Yamnaya, 4 Catacomb culture).
- 1st stage of kurgan 1 erected above 3 Eneolithic graves.

Geology
In the vicinity of the confluence between the tributary Podpolnaya and the rivers Samara and Dnieper. Plain composed of Cenozoic sediments, < 10 km (to the west and east) from outcrops of Proterozoic plutonite.

Samples
- Kurgan group 2 kurgan 1 graves 6, 7, 10, 11, 12, 14, 15.

$^{87}Sr/^{86}Sr$ reference material
Appendix A I Table 8 (p. 345).

References
Unpublished.
Pers. comm. D. Teslenko.

17 Shakhta Stepnaya

Province Dniepropetrovsk, Petropavlovsk region.
Coordinates: 48.38304° N, 36.37159° E.

Archaeology
4 kurgans in a line, of which kurgans 2, 3 and 4 were excavated. Excavations in 2007 by V. A. Romashko:

- kurgan 2: 7 graves (3 Yamnaya, 1 Catacomb, 1 Babino, 2 Srubnaya).
- kurgan 3: 3 graves (2 Yamnaya, 1 Catacomb).
- kurgan 4: 11 graves (2 Eneolithic, 2 Yamnaya, 1 Catacomb, 4 Srubnaya, 1 Late Bronze Age, 1 Medieval).

Geology
On Cenozoic sediments. < 50 km from Carboniferous and Mesozoic outcrops (to the east), and Archaean metamorphic rocks and Proterozoic plutonite outcrops (to the south).

Samples
- Kurgan 2: graves 4, 7.
- Kurgan 4: graves 10, 11.

$^{87}Sr/^{86}Sr$ reference material
Appendix A I Table 9 (p. 346).

References
Excavation report (unpublished):
V. A. Romashko, Otchet o raskopkakh kurganov v zone podrabotki shakhty 'Stepanaya' u s. Nikolaevka Petropavlovskogo raiona Dnepropetrovskoi oblasti v 2008 g. (po otkrytome listu № 366/0430).

18 Vinogradnoe

Province Zaporozhe, Tokmak region.
Coordinates: 47.20505° N, 35.55965° E (village of Vinogradnoe).

Archaeology
Group of several kurgans. Excavations in 1982 (kurgan 3) and 1984 (kurgan 24) by Y. Ya. Rassamakin (Zaporozhe Archaeological Expedition of the Ukrainian Academy of Science):
- Kurgan 3: diam. 100 m, H 8 m, several embankments, 49 graves (6 Eneolithic, 23Yamnaya, 16 Catacomb, 1 Babino, 1 Srubnaya, 2 undefined).
- Kurgan 24: 54 m × 62 m, H 5 m, several embankments, 31 burials (3 Eneolithic, 15Yamnaya, 4 Early Catacomb, 7 Developed Catacomb, 1 Early Iron Age, 1 undefined).

Geology
Situated on the terraces of the river Molochnaya with Cenozoic deposits, adjacent geologically homogeneous plain composed of Cenozoic sediments. ~ 20 km (to the east) from Archaean metamorphic rocks and Proterozoic plutonites.

Samples
- Kurgan 3: graves 15, 25, 36.
- Kurgan 24: graves 8 individual 1 and individual 2, 15 individual 1and individual 2, 17, 19, 22, 26, 30, 31, 32, 34 individual 1 and individual 2.

$^{87}Sr/^{86}Sr$ reference material
Appendix A I Table 10 (p. 346).

References
Kurgan 24:
V. V. Otroshchenko et al., Otchet o raskopkakh Zaporozhskoi ekcpeditsii IA AZ Ukrainy v 1984 godu. Nauchnyi arkhiv IA AN Ukrainy 1984/10.

^{14}C-date (kurgan 24): J. Görsdorf/A. Häusler/D. C. Owen/C. Bronk Ramsey/Y. Rassamakin, ^{14}C Dating of Mound 24 of the Kurgan Group near Vinogradnoe Village, Ukraine. In: T. F. G. Higham/C. Bronk Ramsey/D. C. Owen (Eds.), Radiocarbon and Archaeology: Proceeding of the Fourth International Symposium, St Catherine's College, Oxford (9–14th April, 2002). Monogr. 62 (Oxford 2004) 127–134.

Kurgan 3:
partly published in S. Zh. Pustovalov, Molochanske svyatilishche. Problemy arkheologii Podniprovya 2, 1999, 104–118.

Russia

19 Kalinovka I

Province Samara, Sergievskii region.
Coordinates: 53.83378° N, 51.28899° E (village of Kalinovka).

Archaeology
Group of 11 kurgans, of which 5 are excavated. Excavations in 1998 and 2005 by D. A. Stashenko:

- Kurgan 1: (preserved) diam. 24–26 m, H 0.6 m, 7 graves (5 Poltavka culture, 2 Sarmatian).

Geology
Situated on Permian rocks. Proximal to Cenozoic sediments along one tributary of the Volga, < 50 km from Triassic outcrops (to the west and southeast).

Samples

- Kurgan 1: graves 3, 4, 6.

$^{87}Sr/^{86}Sr$ reference material
Appendix A I Table 11 (p. 347).

References
V. A. A. Khokhlov, Spetsifika fizicheskogo tipa naseleniya srednebronzovogo veka Srednego i Nizhnego Povolzhya (po antropologicheskim materialam kurgannykh mogilnikov Kalinovka I, Podlesnoe, Nikolaevka III, Politotdelskoe). Unpublished report within the project RA A2 Topoi, Berlin.

D. A. Stashenkov/V. A. Skarovenko/S. I. Vasilyeva/P. A. Kosintsev/N. V. Roslyakova/N.P. Salugina, A. A. Khokhlov, Kalinovskii I kurgannyi mogilnik (Samara 2006).

20 Nikolaevka III

Province Samara, Volzhskii region.
Coordinates: 53.09154° N, 50.31464° E (village of Nikolaevka).

Archaeology
Group of 6 kurgans, orientated in a line on 2nd terrace of the river Samara. Excavations in 1995 by V. A. Skarbovenko:

- Kurgan 1: 21 m × 31 m, H 0.37 m, 5 Bronze Age graves.
- Kurgan 2: 24 m × 31 m, H 0.4 m, 1 Bronze Age burial.
- Kurgan 3: 20 m × 28.5 m, H 0.35 m, 4 Bronze Age burials with entrance shafts.
- Kurgan 5: 28 m × 30 m, H 0.3 m, 1 Bronze Age grave.

Geology
Situated on Cenozoic sediments. < 10 km from Permian outcrops (to the north and south); < 50 km from Permian and Mesozoic geology (to the west and east).

Samples

- Kurgan 1: graves 2, 3.
- Kurgan 2: grave 1 individuals 1 and 2.
- Kurgan 3: grave 1 individuals 1 and 2, grave 4.
- Kurgan 5: grave 1.

$^{87}Sr/^{86}Sr$ reference material
Dentine samples: kurgan 1 grave 2, kurgan 3 grave 1, kurgan 5 grave 1.

References
V. A. A. Khokhlov, Spetsifika fizicheskogo tipa naseleniya srednebronzovogo veka Srednego i Nizhnego Povolzhya (po antropologicheskim materialam kurgannykh mogilnikov Kalinovka I, Podlesnoe, Nikolaevka III, Politotdelskoe). Unpublished report within the project RA A2 Topoi, Berlin.

A. Skarbovenko, Nikolaevka III – mogilnik epokhi srednei bronzy v doline r. Samary. In: Voprosy arkheologii Urala i Povolzhya. K 30 letiyu Srednevolzhskoi arkheologicheskoi ekspeditsii (Samara 1999) 143–164.

21 Olennii

Province Krasnodar, Kalininskii region.
Coordinates: 42.19775° N, 26.04652° E.

Archaeology
Group of 3 kurgans. Excavations in 1987 by A. Gei:

- Kurgan 1: diam. 31–33 m, H 2.5 m, 21 burials (different time periods).
- Kurgan 2: diam. ~ 30 m, H 0.8 m, 35 burials (different time periods).
- Kurgan 3: diam. ~ 40 m (destroyed), H 1.2 m, 14 burials (different time periods).

Geology
Very homogeneous lowland plain of Cenozoic sediments. North of the Caucasian Mountains, seasonally covered by the Liman water; < 50 km (to the south) from the Caucasian Mountain ranges with a composition of Cretaceous and Jurassic rocks. Geological homogeneity to the north and east.

Samples

- Kurgan 1: grave 21b.
- Kurgan 2: graves 25b, 26, 35a, 35b.
- Kurgan 3: graves 3, 14a.

$^{87}Sr/^{86}Sr$ reference material
Dentine samples: kurgan 2 graves 25b, 35a, kurgan 3 grave 3.

References
Unpublished.
Pers. comm. A. Gei.

22 Podlesnyi

Province Samara, Volzskii region.
Coordinates: 53.2315° N, 50.50381° E (village of Podlesnyi).

Archaeology
Group of 8 kurgans in a line, of which kurgans 3 and 5 were excavated in 1997 and 2000 by P. P. Barynkin:

- Kurgan 3: diam. 24 m, H 0.2–0.35 m, 7 burials.

Geology
Situated on Cenozoic sediments in the vicinity of a tributary of the river Volga. < 10 km from Permian outcrops; < 50 km from Mesozoic geology.

Samples

- Kurgan 3: graves 3, 5, 6.

$^{87}Sr/^{86}Sr$ reference material
Dentine samples: graves 3, 5, 6.

References
P. P. Barynkin/V. N. Zudina/A. I. Kramarev/N. P. Salugina/V. A. Tsibin/A. A. Khokhlov, Issledovanie kurganov epokhi bronzy u pos. Podlesnyi na r. Samare. Voprosy arkheologii Povolzhya 4, 2006, 293–309.

A. A. Khokhlov, Spetsifika fizicheskogo tipa naseleniya srednebronzovogo veka Srednego i Nizhnego Povolzhya (po antropologicheskim materialam kurgannykh mogilnikov Kalinovka I, Podlesnoe, Nikolaevka III, Politotdelskoe). Unpublished report within the project RA A2 Topoi, Berlin.

23 Politotdel'skoe

Province Volgograd, Nikolaevskii region.
Coordinates: 49.76372° N, 45.39928° E (village of Politotdel'skoe).

Archaeology
Group of 4 kurgans, of which 3 were excavated in 1989 by O. V. Kuzmina:

- Kurgan 2: diam. 13 m, H ~ 0.3 m, 7 Catacomb graves (primary grave 1 not sampled).
- Kurgan 4: > 14 graves.

Geology
Cenozoic sediments along the river Volga. Local geology within a radius of < 50 km characterized by Cretaceous and Cenozoic sediments, and rare inliers of Permian and Jurassic rocks. Some of the Cretaceous rocks are metamorphic.

Samples

- Kurgan 2: graves 2, 3.
- Kurgan 4: grave 6.

$^{87}Sr/^{86}Sr$ reference material
Dentine samples: kurgan 2 graves 2, 3.

References
A. A. Khokhlov, Spetsifika fizicheskogo tipa naseleniya srednebronzovogo veka Srednego i Nizhnego Povolzhya (po antropologicheskim materialam kurgannykh mogilnikov Kalinovka I, Podlesnoe, Nikolaevka III, Politotdelskoe). Unpublished report within the project RA A2 Topoi, Berlin.

O. V. Kuzmina, Otchet o raskopkakh kurgannykh mogilnikov u s. Politotdelskoe i Khokhlaevskii v Nikolaevskom i Sredne-Akhtubinskom raionakh Volgogradskoi oblasti v 1989 g. (R-1, 14291).

24 Sukhaya Termista II

Province Rostov, Remontnoe region.
Coordinates: Kurgan 1: 46.58581° N, 43.63631° E; kurgan 3: 46.58658° N, 43.63825° E.

Archaeology
Group of 5 kurgans, 3 still visible; kurgans on a terrace about 10–15 m above the little stream Dyurak-Sal; 2 kurgans excavated in 2008 by N. I. Shishlina (State Historical Museum, Moscow):

- Kurgan 1: ~ 40 m × 45 m, H 1.1 m, 5 graves (3 Early Catacomb, 1 Manych Catacomb, 1 Lola culture).
- Kurgan 3: ~ 36 m × 23 m, H 1.5 m, N–S oriented (oval shaped), 24 graves (1 Early Catacomb, 23 Medieval).

Geology
Undulating plain in a highly homogeneous geological region of Cenozoic sediments. < 100 km from the compositionally variable Yergueni Hills that include rocks of Cretaceous age.

Samples

- Kurgan 1: graves 2, 3, 5.
- Kurgan 3: grave 20.

$^{87}Sr/^{86}Sr$ reference material
Appendix A I Table 12 (p. 347).

References
Unpublished.
Pers. comm. N. I. Shishlina.

Iron Age

Ukraine

25 Alexandropol'

Province Dniepropetrovsk, Solenoe region.
Coordinates: 48.01403° N, 34.44318° E.

Archaeology
Single kurgan, 5 Bronze Age burial mounds in vicinity.
Excavations: central burial in 1855 and 1856, excavations of the secondary burials 2004 to 2009 by S. Polin (Ukrainian Academy of Sciences):

- Kurgan: diam. 100 m, H 21 m, 11 secondary burials in the periphery of the burial mound with its monumental central grave.

Geology
Geologically homogenous plain of mostly Cenozoic sediments, but also Archaean metamorphic rocks and Proterozoic plutonites.

Samples

- Secondary burials: trench 5 grave 1, trench 10 grave 3, trench 12 grave 4, trench 15 graves 6 and 8.

$^{87}Sr/^{86}Sr$ reference material
Appendix A I Table 13 (p. 347).

References
Polin/Daragan, 2011.

Pers. comm. S. Polin on basis of excavation report and anthropological report in Kiev, Institute of Archaeology, National Academy of Sciences in Ukraine.

26 Babina Mogila

Province Dniepropetrovsk, Apostolovo region.
Coordinates: 47.8136° N, 33.93832° E.

Archaeology
Necropolis includes 11 small burial mounds (most of them destroyed by agricultural activity), 2 of the mounds can be dated to the Bronze Age, the others to the Scythian period.
Excavations in 1986 by S. Polin:

- Kurgan 'Babina Mogila': diam. 60 m, H 8.15 m, looted, 1 complex central grave with 3 grave chambers containing 7 skeletons.

Geology
Situated on Cenozoic sediments; regional geology a mixture of Cenozoic sediments, Proterozoic plutonites and Archaean metamorphic rocks.

Samples

- Kurgan 'Babina Mogila': burial chambers 1 and 3.

$^{87}Sr/^{86}Sr$ reference material
Dentine samples: graves 1, 3.

References
S. I. Kruts, Babina, Vodjana i soboleva mogily. In: B. N. Mozolevskij/S. V. Polin, Kurgany skifskogo Gerosa IV v. do n.e. (Kiev 2005) 460–461.

27 Drana Kokhta

Province Dniepropetrovsk, Apostolovo region.
Coordinates: 47.80251° N, 33.8867° E.

Archaeology
Kurgan group of 15 Bronze and Iron Age burial mounds. Excavations in 1974 and 1975 by B. N. Mozolevskii:

- Kurgan: diam. 76 m, H 9.2 m, 5 graves (4 Scythian, 1 Medieval).

Geology
Situated on Proterozoic plutonites: regional geology a mixture of Cenozoic sediments, Proterozoic plutonites and Archaean metamorphic rocks.

Samples
- Central burial and niche 5.

$^{87}Sr/^{86}Sr$ reference material
Dentine samples: central burial and niche 5.

References
Published as Zheltokamenka in:
B. N. Mozolevskii, Skifskii 'tsarskii' kurgan Zheltokamenka. In: Drevnosti stepnoi skifi (Kiev 1982).

28 Ordzhonikidze

Province Dniepropetrovsk, Nikopol region.
Coordinates: 47.66028° N, 34.06208° E (village of Ordzhonikidze).

Archaeology
Several groups of burial mounds. Excavations in 1998 and 2007 by S. Polin (Ukrainian Academy of Sciences):
- Kurgan 15 belongs to the group of burial mounds Balka Krinichevataya (11 kurgans, 4 investigated, of which 3 dated to the Scythian period, 1 to the Bronze Age).
- Kurgans 32 and 33 belong to the kurgan group near Staraya Katerovka (11 kurgans, 4 investigated, of which 2 date to the Scythian period and 2 to the Bronze Age).

Geology
Situated on Proterozoic plutonites; regional geology a mixture of Cenozoic sediments, Proterozoic plutonites and Archaean metamorphic rocks.

Samples
- Kurgan 15: graves 1, 2.
- Kurgan 32: grave 4 gracile skeleton and robust skeleton.
- Kurgan 33: graves 1, 3.

$^{87}Sr/^{86}Sr$ reference material
Appendix A I Table 14 (p. 348).

References
Unpublished.

Anthropological information: Pers. comm. S. Polin based on excavation report and anthropological report in Kiev, Institute of Archaeology, National Academy of Sciences in Ukraine.

29 Zolotaya Balka

Province Cherson, Novovorontsovskii region.
Coordinates: 47.37868° N, 33.96404° E.

Archaeology
Group of 22 kurgans.
Excavations in 1982 by S. Polin (Ukrainian Academy of Sciences).

Geology
In vicinity of the river Dnieper on Cenozoic sediments in an area dominated by young sediments. < 20 km from Proterozoic plutonites.

Samples
- Kurgan 13: grave 1.
- Kurgan 15: graves 1, 2, 3.
- Kurgan 22: grave 1.

$^{87}Sr/^{86}Sr$ reference material
Dentine samples: kurgan 13 grave 1, kurgan 15 grave 2.

References
Unpublished.

Kazakhstan

30 Berel'

Province Uryl, Katon-Karagai region.
Coordinates: 49.34361° N, 86.36522° E.

Archaeology
Large group of several dozen burial mounds. Excavations in the mid-19th century by V. V. Radloff; new excavations 1998–2007.

Geology
Palaeozoic geology, Cenozoic sediments to the south, Precambrian geology to the north.

Samples
- Humans: kurgans 9, 10, 16, 32, 34, 72.
- Horses: kurgans 9, 10, 11, 18, 23.

$^{87}Sr/^{86}Sr$ reference material
Appendix A I Table 15 (p. 348).

References
Keyser-Tracqui et al., 2005.

Samashev et al., 2002.

Samashev, 2007.

Samashev, 2011.

Pers. comm. G. Bazarbayeva and Z. Samashev.

Case Study Chapter 5:
Globular Amphora Culture

Germany

31 Zauschwitz

District of Borna, Leipzig region, Saxony.
Coordinates: 51.18215° N, 12.26152° E.

Archaeology
Excavations in 1960 and 1961: triple cattle burial of the Globular Amphora Culture in 1960; human double burial by K. Fritzsche, Landesmuseum für Vorgeschichte, Dresden, in 1961. Diachronic archaeological site.

Geology
Situated on Cenozoic sediments. < 20 km from Palaeozoic and Mesozoic geology (to the north and west); further south, south-east and east are Proterozoic and Cambrian metamorphic rocks, Palaeozoic plutonites and Ordovician and Carboniferous geology; Triassic geology lies to the west; a plain with young sediments lies to the north.

Samples
- Human double burial: individuals east and west.
- Triple cattle burial: cattle I, II, III.

$^{87}Sr/^{86}Sr$ reference material
Appendix A I Table 16 (p. 348).

References
Coblenz/Fritsche, 1961.

Coblenz/Fritsche, 1962.

Weber, 1964, 137–147, fig. 44–52.

$^{87}Sr/^{86}Sr$ reference material

Appendix A I Table 1 | Benkovski, $^{87}Sr/^{86}Sr$ reference material.

ID	item	distance to site	identical geology	risk of contamination	description	$^{87}Sr/^{86}Sr$	2 S.E.
S 13A	sediment	0 m	x	low	backfilling of kurgan 1, grave 2	0.70824	0.00001
S 13B	sediment	0 m	x	low	backfilling of kurgan 1, grave 2	0.70822	0.00001
P 9	plant	100–150 m	probably	high (cultivated)	–	0.70745	0.00001
Bu Ref 1	fauna	3 km N of Benkovski	probably	? (excavation Sabrono, pit 15)	pig tooth (M1)	0.70841	0.00001
+ Dentine samples: kurgan 1 graves 2 and 3, kurgan 2 graves 3 and 7							

Appendix A I Table 2 | Boyanovo, $^{87}Sr/^{86}Sr$ reference material.

ID	item	distance to site	identical geology	risk of contamination	description	$^{87}Sr/^{86}Sr$	2 S.E.
S 20A	sediment	< 50 m	x	low	heterogeneous	0.70892	0.00001
S 20B	sediment	< 50 m	x	low	heterogeneous	0.70894	0.00001
Bo Ref 1	fauna	100 m	x	high	modern snails from a cultivated area	0.70818	0.00001
Bu Ref 3	fauna	10 km S of Boyanovo	?	? (excavation Elhovo)	pig tooth (M3)	0.70815	0.00001
+ Dentine samples: graves 4, 5, 14 skeleton 1							

Appendix A I Table 3 | Ovchartsi, $^{87}Sr/^{86}Sr$ reference material.

ID	item	distance to site	identical geology	risk of contamination	description	$^{87}Sr/^{86}Sr$	2 S.E.
S 12A	sediment	250–300 m	?	(mining area)	–	0.70787	0.00001
S 12B	sediment	250–300 m	?	(mining area)	–	0.70782	0.00001
P 8	plant	150–200 m	?	(mining area)	–	0.70974	0.00001
+ Dentine samples: 'The Big Tumulus' graves 1, 2, 15							

Appendix A I Table 4 | Smyadovo, $^{87}Sr/^{86}Sr$ reference material.

ID	item	distance to site	identical geology	risk of contamination	description	$^{87}Sr/^{86}Sr$	2 S.E.
S 8A	sediment	3–4 m	x	high (cultivated)	loamy	0.70780	0.00026
S 8B	sediment	3–4 m	x	high (cultivated)	loamy	0.70777	0.00001
P 10	plant	3–4 m	x	high (cultivated)	–	0.70812	0.00007
Bu Ref 2	fauna	?	probably	low (excavation Smyadovo-Maluolitu)	pig tooth (*sus scrofa*?) M1	0.70818	0.00015
+ Dentine samples: graves 11, 13, 26							

Appendix A I Table 5 | Sárrétudvari-Őrhalom, $^{87}Sr/^{86}Sr$ reference material.

ID	item	distance to site	identical geology	risk of contamination	description	$^{87}Sr/^{86}Sr$	2 S.E.
S 6A	sediment	< 5 km	probably	high (fertilizers)	cultivated field	0.71155	0.01640
S 6B	sediment	< 5 km	probably	high (fertilizers)	cultivated field	0.71122	0.00025
P 1	plant	< 5 km	probably	low		0.71053	0.00001
Hu 21	fauna	0 m (grave 8)	yes	diagenesis	sheep bone, grave 8	0.71021	0.00001
Hu 22	fauna	? (field survey 2/1997, vicinity of Őrhalom)	probably	diagenesis	sheep bone	0.71043	0.00001
Hu 23	fauna	? (field survey 1988, N of Őrhalom)	probably	?	cattle tooth	0.70896	0.00001
+ Dentine samples: graves 9, 10, 11, 12							

Appendix A I Table 6 | Kétegyháza-Kétegyházi tanyák, $^{87}Sr/^{86}Sr$ reference material.

ID	item	distance to site	identical geology	risk of contamination	description	$^{87}Sr/^{86}Sr$	2 S.E.
Ke 1	fauna	0 m (kurgan 3, grave 7)	x	low	dog tooth (prehistoric)	0.70936	0.00001
Ke 2	fauna	0 m (kurgan 3b, grave 1)	x	diagenesis	sheep astragalos (prehistoric)	0.70925	0.00001
+ Dentine samples: kurgan 6 graves 1, 3							

Appendix A I Table 7 | Kirovograd, $^{87}Sr/^{86}Sr$ reference material.

ID	item	distance to site	identical geology	risk of contamination	description	$^{87}Sr/^{86}Sr$	2 S.E.
S 1A	sediment	< 5 km	?	low	uncultivated area, –1 m	0.71048	0.00001
S 1B	sediment	< 5 km	?	low	uncultivated area, –1 m	0.71013	0.00001
S 5A	sediment	< 5 km	?	high	cultivated field, –1 m	0.71039	0.00001
S 5B	sediment	< 5 km	?	high	cultivated field, –1 m	0.71034	0.00001
P 6	plant	< 5 km	?	low	oak leaves from forest	0.71008	0.00001
Su 1	fauna	0 km	yes	low	horse tooth, grave 5, enamel vertical	0.71038	0.00001
Su 1.1	fauna	0 km	yes	low	horse tooth, grave 5, enamel cusp horizontal	0.71041	0.00001
Su 1.2	fauna	0 km	yes	low	horse tooth, grave 5, enamel centre horizontal	0.71033	0.00001
Su 1.3	fauna	0 km	yes	low	horse tooth, grave 5, enamel cervix horizontal	0.71042	0.00001
Su 1C	fauna	0 km	yes	low	horse tooth, grave 5, dentine	0.71029	0.00001
Su Ref 2	fauna	< 5 km	?	low	snail (recent)	0.71019	0.00001
+ Dentine samples: graves 10 child, 20, 24; bone samples: graves 13, 24							

Appendix A I Table 8 | Peshtchanka, $^{87}Sr/^{86}Sr$ reference material.

ID	item	distance to site	identical geology	risk of contamination	description	$^{87}Sr/^{86}Sr$	2 S.E.
S 10A	sediment	< 10 m	yes	medium (fertilizers)	in vicinity of kurgan, –0.8 m	0.71095	0.00001
S 10B	sediment	< 10 m	yes	medium (fertilizers)	in vicinity of kurgan, –0.8 m	0.71079	0.00003
S 15A	sediment	< 10 m	yes	medium (fertilizers)	in vicinity of kurgan, –1 m	0.71114	0.00004
S 15B	sediment	< 10 m	yes	medium (fertilizers)	in vicinity of kurgan, –1 m	0.71079	0.00001
P 4	plant	< 10 m	yes	medium (fertilizers)	plant	0.71072	0.00001
Pr 1	fauna	< 100 m	yes	supplementary feeding?	cattle tooth (M1), excavation (18th century, Peshtchanka)	0.71142	0.00001
Pr 2	fauna	< 100 m	yes	supplementary feeding?	cattle tooth (M3), excavation (18th century, Peshtchanka)	0.71160	0.00001
+ Dentine samples: graves 6, 14; bone samples: graves 10, 11							

Appendix A I Table 9 | Shakhta Stepnaya, $^{87}Sr/^{86}Sr$ reference material.

ID	item	distance to site	identical geology	risk of contamination	description	$^{87}Sr/^{86}Sr$	2 S.E.
S 7A	sediment	0 m	yes	medium (fertilizers)	from remains of kurgan 4, –1 m	0.71027	0.00001
S 7B	sediment	0 m	yes	medium (fertilizers)	from remains of kurgan 4, –1 m	0.71021	0.00001
P 5	plant	< 100 m	yes	medium (fertilizers)	oak leaves	0.71094	0.00001
SS Ref 35	fauna	0 m	yes	low	shell, from remains of kurgan 4	0.70914	0.00001
+ Dentine and bone samples: kurgan 2 grave 4, kurgan 4 grave 10							

Appendix A I Table 10 | Vinogradnoe, $^{87}Sr/^{86}Sr$ reference material.

ID	item	distance to site	identical geology	risk of contamination	description	$^{87}Sr/^{86}Sr$	2 S.E.
S 2A	sediment	?	yes	low	kurgan east of Capevka, looters' pit	0.71016	0.00001
S 2B	sediment	?	yes	low	kurgan east of Capevka, looters' pit	0.71005	0.00001
S 3A	sediment	?	probably	high (fertilizers)	Zamoznoe, black earth from field	0.70993	0.00001
S 3B	sediment	?	probably	high (fertilizers)	Zamoznoe, black earth from field	0.70987	0.00001
S 4A	sediment	?	yes	low	near Vinogradnoe, loam pit	0.71041	0.00001
S 4B	sediment	?	yes	low	near Vinogradnoe, loam pit	0.71021	0.00001
P 3	plant	?	yes	low	near Vinogradnoe, loam pit	0.71025	0.00001
Vi Ref 20	fauna	?	yes	high (fertilizers)	rodent tooth (recent), near kurgan east of Capevka	0.70762	0.00001
Vi Ref 18b	fauna	?	yes	low	shell, near Vinogradnoe, loam pit	0.71192	0.00001
Vi Ref 18	fauna	?	yes	low	rodent tooth (recent), near Vinogradnoe, loam pit	0.71008	0.00001
Zn 1	fauna	?	?	?	Zamoznoe, Medieval grave, dog tooth (PM 4)	0.70967	0.00001
Zn 2	fauna	?	?	?	Zamoznoe, Medieval grave, dog tooth (M1)	0.70966	0.00001
+ Dentine samples: kurgan 24 graves 8, 19, 26; bone samples: kurgan 3 graves 15, 25, kurgan 24 graves 8, 17							

Appendix A I Table 11 | Kalinovka I, $^{87}Sr/^{86}Sr$ reference material.

ID	item	distance to site	identical geology	risk of contamination	description	$^{87}Sr/^{86}Sr$	2 S.E.
Wo B1	fauna	0 m	x	diagenesis	animal bone, grave 5	0.70929	0.00001
Wo B2	fauna	0 m	x	diagenesis	animal bone, grave 4	0.70908	0.00001
+ Dentine samples: graves 3, 4							

Appendix A I Table 12 | Sukhaya Termista II, $^{87}Sr/^{86}Sr$ reference material.

ID	item	distance to site	identical geology	risk of contamination	description	$^{87}Sr/^{86}Sr$	2 S.E.
S 9 B	sediment	0 m	x	–	kurgan 1, grave 1, grave fill	0.70898	0.00001
Re Ref 9	fauna	< 50 m	x	? (supplementary feeding?)	cattle tooth (recent), horizontal section, vicinity of kurgan	0.70905	0.00001
Re Ref 11	fauna	< 20 m	x	? (fertilizers)	rodent tooth (recent), vicinity of kurgan	0.70921	0.00001
Re Ref 12	fauna	0 m	x	? (fertilizers)	rodent tooth (recent), vicinity of kurgan	0.70925	0.00001
Re Ref 112	fauna	0 m	x	? (fertilizers)	rodent tooth (recent), vicinity of kurgan	0.70926	0.00001
Re Ref 14	fauna	< 20 m	x	? (fertilizers)	rodent tooth (recent), vicinity of kurgan	0.70934	0.00001
+ Bone samples: kurgan 1 graves 2, 3, kurgan 3 grave 20							

Appendix A I Table 13 | Alexandropol', $^{87}Sr/^{86}Sr$ reference material.

ID	item	distance to site	identical geology	risk of contamination	description	$^{87}Sr/^{86}Sr$	2 S.E.
S 11A	sediment	0 m (central grave)	x	low	grave fill	0.71005	0.00001
S 11B	sediment	0 m (central grave)	x	low	grave fill	0.70998	0.00001
S 16A	sediment	0 m (central grave)	x	low	loam	0.71007	0.00001
S 16B	sediment	0 m (central grave)	x	low	loam	0.70982	0.00001
S 21A	sediment	0 m (trench 17)	x	low	homogeneous soil	0.71032	0.00001
S 21B	sediment	0 m (trench 17)	x	low	homogeneous soil	0.71033	0.00001
Al Ref 1	fauna	0 m (trench 17)	x	?	rodent tooth (recent)	0.71020	0.00001
+ Dentine samples: trench 5 grave 1, trench 12 grave 4, trench 15 grave 6							

Appendix A I Table 14 | Ordzhonikidze, $^{87}Sr/^{86}Sr$ reference material.

ID	item	distance to site	identical geology	risk of contamination	description	$^{87}Sr/^{86}Sr$	2 S.E.
O Ref 1	fauna	0 m (kurgan 18, grave 20)	x	diagenesis	sheep bone	0.70981	0.00001
+ Dentine samples: kurgan 15 grave 1, kurgan 33 grave 3							

Appendix A I Table 15 | Berel', $^{87}Sr/^{86}Sr$ reference material.

ID	item	distance to site	identical geology	risk of contamination	description	$^{87}Sr/^{86}Sr$	2 S.E.
S 22A	sediment	0 m (kurgan 75, sector D)	x	low	homogeneous soil	0.71081	0.00001
S 22B	sediment	0 m (kurgan 75, sector D)	x	low	homogeneous soil	0.71066	0.00001
S 23A	sediment	0 m (kurgan 8, NW-sector)	x	low	homogeneous soil	0.71092	0.00014
S 23B	sediment	0 m (kurgan 8, NW-sector)	x	low	homogeneous soil	0.71067	0.00001
+ Dentine samples: humans kurgans 9, 10, 16, 32, 34, 72, horses kurgans 9, 10, 11, 18, 23							

Appendix A I Table 16 | Zauschwitz, $^{87}Sr/^{86}Sr$ reference material.

ID	item	distance to site	identical geology	risk of contamination	description	$^{87}Sr/^{86}Sr$	2 S.E.
Z 8	snail	0 m	yes	possible (modern)	snail (recent)	0.71063	0.00001
Z 9	snail	0 m	yes	possible (modern)	snail (recent)	0.71080	0.00001
+ Dentine samples: human individuals east and west							

II Samples

Order of sample sites as listed in Appendix A II Table 1:

Eneolithic and Bronze Age

- Bulgaria
  - Benkovski
  - Boyanovo
  - Ovchartsi
  - Smyadovo
- Hungary
  - Sárrétudvari-Őrhalom
  - Kétegyháza-Kétegyházi tanyák
  - Further sites
- Ukraine
  - Kirovograd
  - Nevskoe
  - Peshtchanka
  - Shakhta Stepnaya
  - Vinogradnoe
- Russia
  - Kalinovka I, Politotdel'skoe
  - Nikolaevka III
  - Olennii
  - Podlesnyi
  - Sukhaya Termista II

Iron Age

- Ukraine
  - Alexandropol'
  - Babina Mogila
  - Drana Kokhta
  - Ordzhonikidze
  - Zolotaya Balka
- Kazakhstan
  - Berel'

Case Study Chapter 5: Globular Amphora Culture

- Germany
  - Zauschwitz

Appendix A II Table 1 | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_C$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
Benkovski																								
Ben 1	1	2		pit	rectangular	SW–NE	EBA	x	single					supine with crouched legs		*maturus* 40–50 years	male	maxilla M1	0.70829	0.00001	97	–3.29	–	–
Ben 2	1	3		pit	rectangular?	S–N	EBA		single					supine with crouched legs (destroyed)				mandibula M1	0.70815	0.00001	218	–3.38	–	–
Ben 3	2	1		pit	rectangular	W–E	EBA	?	single					supine with crouched legs	4172 ± 28 (OxA-23064)	juvenile ~ 16 years	male ?	maxilla r M2	0.70813	0.00001	424	–4.04	9.6	–19.0
Ben 4	2	2		pit	oval	W–E	EBA	?	single					supine with crouched legs	4190 ± 27 (OxA-23081)	*maturus* 50–55 years	male	maxilla l M1	0.70812	0.00001	247	–4.08	9.9	–18.3
Ben 5	2	2		pit	oval	W–E	EBA	?	single					supine with crouched legs	4190 ± 27 (OxA-23081)	*maturus* 50–55 years	male	maxilla r M3	0.70806	0.00001	307	–4.94	9.9	–18.3
Ben 11	2	3		pit	rectangular	SW–NE	EBA	?	single				ceramic fragment	supine with crouched legs		juvenile ~ 16 years	male ?	maxilla l M1	0.70926	0.00001	140	–4.34	–	–
Ben 6	2	3		pit	rectangular	SW–NE	EBA	?	single				ceramic fragment	supine with crouched legs		juvenile ~ 16 years	male ?	mandibula r M2	0.70916	0.00001	189	–5.18	–	–
Ben 7	2	4		pit	rectangular	W–E	EBA	?	single			x		crouched (on the back?)		*Infans* II 10–11 years		mandibula M1	0.70811	0.00001	337	–4.03	–	–
Ben 8	2	6		pit	rectangular	SW–NE	EBA	?	single					crouched (on the back?)		*maturus* 40–45 years	male	mandibula r M1	0.70806	0.00001	482	–3.57	–	–
Ben 9	2	7		pit	rectangular	E–W	EBA	?	single			x		(destroyed)				mandibula M1	0.70809	0.00001	369	–4.74	–	–
Ben 10	2	9		pit	(not visible)	E–W	EBA	?	single					(destroyed)		*adultus* 20–40 years	male	maxilla r M1 (M2?)	0.70812	0.05665	405	–4.20	–	–
dentine																								
Ben 1c	1	2		pit	rectangular	SW–NE	EBA	x	single					supine with crouched legs		*maturus* 40–50 years	male	maxilla M1	0.70821	0.00001	1390	–	–	–
Ben 2c	1	3		pit	rectangular?	S–N	EBA		single					supine with crouched legs (destroyed)				mandibula M1	0.70824	0.00001	617	–	–	–
Ben 6c	2	3		pit	rectangular	SW–NE	EBA	?	single				ceramic fragment	supine with crouched legs		juvenile ~ 16 years	male ?	mandibula r M2	0.70810	0.00001	4540	–	–	–
Ben 9c	2	7		pit	rectangular	E–W	EBA	?	single					(destroyed)				mandibula M1	0.70805	0.00001	5150	–	–	–

Notes:
Anthropological identification by N. Atanassova-Timeva, B. Galabova.
Anthropology: bad preservation of bone, sex and age determined by features of the skull and long bone development.
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Boyanovo																							
lab ID	**kurgan**	**grave**	**individual**	**tomb type**	**grave shape**	**orientation**	**relative date**	**primary burial**	**burial**	**cover**	**organic mat**	**ochre spread**	**burial objects**	**position of skeleton**	**absolute date (BP)**	**age at death**	**sex**	**sampled tooth**	$^{87}Sr/^{86}Sr$	**2 S.E.**	**Sr concentration (ppm)**	$\delta^{18}O_C$ **(‰ vs. V-PDB)**	$\delta^{15}N$ **(bone, ‰ vs. AIR)**	$\delta^{13}C$ **(bone, ‰ vs. V-PDB)**
Bo 3	Lozynskaya Tumulus	4		pit	round	SW–NE	MBA		single		x		ceramic vessel	crouched on the right side		*	*	mandibula M1	0.70770	0.00001	133	–3.75	9.0	–17.2
Bo 11	Lozynskaya Tumulus	4		pit	round	SW–NE	MBA		single		x		ceramic vessel	crouched on the right side		*	*	mandibula M2	0.70930	0.00001	58	–4.00	9.0	–17.2
Bo 1	Lozynskaya Tumulus	5		pit	oval	W–E	EBA (Yamnaya)		single	x (wood)	x		unworked stone, ochre piece	supine with crouched legs		*	*	maxilla M1	0.70867	0.00001	88	–5.60	10.0	–16.0
Bo 4	Lozynskaya Tumulus	6		pit	ellipsoid	W–E	EBA (Yamnaya)		single	x (wood)	x		ochre piece	supine with crouched legs		*	*	maxilla M2	0.70878	0.00001	80	–4.92	10.9	–17.0
Bo 2	Lozynskaya Tumulus	14	1	pit	oval	SW–NE	EBA (Yamnaya)		double	x (wood)			(silver hair ring, ochre piece)	supine with crouched legs	(4186 ± 27)** (OxA-22951)	*	* (male)	mandibula M1	0.70938	0.00001	52	–4.00	10.7	–17.3
Bo 12	Lozynskaya Tumulus	14	1	pit	oval	SW–NE	EBA (Yamnaya)		double	x (wood)			(silver hair ring, ochre piece)	supine with crouched legs	(4186 ± 27)** (OxA-22951)	*	* (male)	mandibula? M3	0.70774	0.00001	101	–4.41	10.7	–17.3
Bo 5	Lozynskaya Tumulus	14	2	pit	oval	SW–NE	EBA (Yamnaya)		double	x (wood)			silver hair ring, ochre piece	crouched on the right side	4186 ± 27 (OxA-22951)	*	* (female)	mandibula M1	0.70910	0.00001	93	–3.42	10.0	–16.0
dentine																								
Bo 3c	Lozynskaya Tumulus	4		pit	round	SW–NE	MBA		single		x		ceramic vessel	crouched on the right side		*	*	mandibula M1	0.70812	0.00001	231	–	–	–
Bo 1c	Lozynskaya Tumulus	5		pit	oval	E–W	EBA (Yamnaya)		single	x (wood)	x		unworked stone, ochre piece	supine with crouched legs		*	*	maxilla M1	0.70864	0.00001	140	–	–	–
Bo 2c	Lozynskaya Tumulus	14	1	pit	oval	E–W	EBA (Yamnaya)		double	x (wood)			(silver hair ring, ochre piece)	supine with crouched legs	(4186 ± 27)** (OxA-22951)	*	* (male)	mandibula M1	0.70861	0.00001	239	–	–	–

Notes:
* not aged and sexed
** date obtained from grave 14 skeleton 2
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Ovchartsi																							
lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_C$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
OV 1	Tumulus in the Vineyards	3		pit	rectangular	E–W	EBA (Yamnaya)	x	single				stone tool, 2 animal bones, charcoal on the left hand	supine with crouched legs		juvenile ~ 17 years	male	maxilla M1	0.70976 (re-analysis: 0.70976)	0.00001 (re-analysis: 0.00001)	203	–4.49	–	–
OV 5	The Big Barrow	1		pit	rectangular	SW–NE	EBA (Yamnaya)		single				(partly destroyed)	?		adult	male?	mandibula M1	0.70906	0.00001	98	–3.52	–	–
OV 12	The Big Barrow	1		pit	rectangular	SW–NE	EBA (Yamnaya)		single				(partly destroyed)	?		adult	male?	mandibula M1	0.70910	0.00001	103	–3.92	–	–
OV 4	The Big Barrow	2	skull south	pit	rectangular	SE–NW	EBA (Yamnaya)		double				ceramics (bowl)	?				maxilla M1	0.70977	0.00001	125	–5.18	–	–
OV 6	The Big Barrow	9		pit	oval	SE–NW	EBA (Yamnaya)		single			x	ceramics (bowl type *Michalič*; cup with ochre pieces, 3 bones, charcoal)	supine with crouched legs	4328 ± 29 (OxA-23063)	*maturus* 40–50 years	male	maxilla M1	0.70961	0.00003	–	–3.60	12.0	–19.0
OV 2	The Big Barrow	9		pit	oval	SE–NW	EBA (Yamnaya)		single			x	ceramics (bowl type *Michalič*; cup with ochre pieces, 3 bones, charcoal)	supine with crouched legs	4328 ± 29 (OxA-23063)	*maturus* 40–50 years	male	maxillaM3	0.71006	0.00001	156	–4.00	12.0	–19.0
OV 3	The Big Barrow	15	skull west	pit	rectangular	N–S	EBA (Yamnaya)		double			x (legs)	ceramics (ceramic bowl, fragments of a pot)	supine with crouched legs		*adultus* 30–35 years	male	mandibula l M1	0.70861	0.00001	158	–4.00	–	–
OV 11	The Big Barrow	15	skull west	pit	rectangular	N–S	EBA (Yamnaya)		double			x (legs)	ceramics (ceramic bowl, fragments of a pot)	supine with crouched legs		*adultus* 30–35 years	male	mandibula l M3	0.70843	0.00001	176	–4.00	–	–
dentine																								
OV 5c	The Big Barrow	1		pit	rectangular	SW–NE	EBA (Yamnaya)		single				– (partly destroyed)	?		adult	male?	mandibula M1	0.70994	0.00001	423	–	–	–
OV 4c	The Big Barrow	2	skull south	pit	rectangular	SE–NW	EBA (Yamnaya)		double				ceramics (bowl)	?				maxilla M1	0.70995	0.00001	251	–	–	–
OV 3c	The Big Barrow	15	skull west	pit	rectangular	N–S	EBA (Yamnaya)		double			x (legs)	ceramics (ceramic bowl, fragments of a pot)	supine with crouched legs		*adultus* 30–35 years	male	mandibula l M1	0.70981	0.00001	482	–	–	–

Notes:
The Big Barrow: primary burial gr. 13
ceramic bowl type Michalič: Ezero
drawings, no descriptions
Anthropology: bad preservation of bone, sex and age determined by features of the skull and long bone development.
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Smyadovo																							
lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_C$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
SM 8		6		pit	(not visible)	SE–NW	EN	?	single				ceramics (4 vessels), stone axe, spondylus, piece of copper, ochre pieces	crouched on the left		*adultus* 25 years	male	maxilla M1?	0.70908	0.00001	113	–6.71	9.0	–20.0
SM 12		6		pit	(not visible)	SE–NW	EN	?	single				ceramics (4 vessels), stone axe, spondylus, piece of copper, ochre pieces	crouched on the left		*adultus* 25 years	male	? M3	0.70878	0.00001	124	–6.41	9.0	–20.0
SM 4		10		pit	oval-rectangular	E–W	EN	?	single				ceramics, ochre pieces	crouched on the left		*adultus* 20–25 years	male	mandibula r M1	0.70816	0.00001	150	–5.83	9.0	–20.0
SM 2		11		pit	rectangular	SW–NE	EN	?	single				ceramics, copper fragment, bone awl	crouched on the left		*adultus* 25–30 years	female	mandibula r M1	0.70818	0.00001	123	–	9.2	–20.3
SM 5		13		pit	(not visible)	E–W	EN	?	single				ceramics	crouched on the left		*adultus* 20–25 years	male	mandibula M1	0.70890	0.00001	150	–6.68	8.0	–20.0
SM 6		15		pit	round	E–W	EN	?	single				ceramics, ochre pieces	crouched on the left		*Infans I* 6 years	?	maxilla M1	0.70819	0.00001	139	–5.62	–	–
SM 7		16		pit	(not visible)	E–W	EN	?	single				ceramics, ochre pieces	crouched on the left		*adultus* 25–30 years	male	mandibula M1	0.70889	0.00001	224	–6.11	–	–
SM 1		22		pit	(not visible)	E–W	EN	?	single				ceramics, spondylus	crouched on the left		juvenile 16–17 years	?	maxilla M1	0.70640 (re-analysis: 0.70640)	0.00001 (re-analysis: 0.00001)	229	–3.84	9.3	–20.0
SM 11		22		pit	(not visible)	E–W	EN	?	single				ceramics, spondylus	crouched on the left		juvenile 16–17 years	?	mandibula M3	0.70672	0.00001	263	–5.56	9.3	–20.0
SM 3		26		pit	(not visible)	E–W	EBA	?	single			x	ceramics, bone artefact, ochre piece	crouched position	4394 ± 29 (OxA-23059)	*adultus* 20–25 years	female	mandibula M3	0.70852	0.00001	189	–5.42	9.0	–20.0
dentine																								
SM 2c		11		pit	rectangular	SW–NE	EN	?	single				ceramics, copper fragment, bone awl	crouched on the left		*adultus* 25–30 years	female	mandibula r M1	0.70821	0.00001	301	–	–	–
SM 5c		13		pit	(not visible)	E–W	EN	?	single				ceramics	crouched on the left		*adultus* 25–30 years	male	mandibula M1	0.70851	0.00001	280	–	–	–
SM 3c		26		pit	(not visible)	E–W	EN	?	single			x	ceramics, bone artefact, ochre piece	crouched position	4394 ± 29 (OxA-23059)	*adultus* 25–30 years	female	mandibula M3	0.708296	0.00001	258	–	–	–

Notes:
Anthropological identification by Y. Yordanov, B. Dimitrova.
Anthropology: bad preservation of bone, sex and age determined by features of the skull and long bone development.
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Sarretudvari-Örhalom																							
lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_C$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
HU 25		4		pit	irregular	ENE–WSW	EBA*		single		x		2 *Lockenringe*, ceramic vessel, animal bone	crouched on the left	4135±60 BP (deb-7182)	40–59 years	male	maxilla l M1	0.71102	0.00001	110	–6.24	–	–
HU1		4		pit	irregular	ENE–WSW	EBA*		single		x		2 *Lockenringe*, ceramic vessel, animal bone	crouched on the left	4135±60 BP (deb-7182)	40–59 years	male	maxilla M3	0.71090	0.00001	82	–6.98	–	–
HU2		7		pit	rectangular	NE–SW	EBA*		double		x		2 *Lockenringe*, ceramic vessel, copper axe, copper dagger, ochre piece	supine?		40–59 years	male	mandibula M2(?)	0.71101	0.00001	96	–6.78	–	–
HU 3		7a		pit	rectangular	NE–SW	EBA*		double		x		2 *Lockenringe*, ceramic vessel, copper axe, copper dagger, ochre piece	?		5–7 years	?	M1	0.71016	0.00001	163	–4.00	–	–
HU 27		7a		pit	rectangular	NE–SW	EBA*		double		x		2 *Lockenringe*, ceramic vessel, copper axe, copper dagger, ochre piece	?		5–7 years	?	M2	0.71021	0.00001	202	–4.38	–	–
HU4		8		pit	?	NW–SE/ SE–NW	EBA*		single		x		? (destroyed)	?		young adult	?	M1	0.71033	0.00001	129	–4.00	–	–
HU 26		8		pit	?	NW–SE/ SE–NW	EBA*		single		x		? (destroyed)	?		young adult	?	mandibula l(?) M2	0.71038	0.00001	138	–4.67	–	–
HU5		9		pit	oval	NNW–SSE(?)	EBA*		single		x		ceramic vessel (dog tooth in grave fill)	supine, legs in 'frog fork' position	4060±50 BP (deb-6871)	23–30 years	male	mandibula M3(?)	0.71097	0.00001	114	–6.46	–	–
HU6		10		pit	?	W–E	EBA*		single				grinding stone (cattle and horse bones in grave fill)	crouched on the right	4350±40 BP (deb-6639)	44–50 years	male	maxilla M2	0.71046	0.00001	63	–4.00	–	–
HU7		11		pit	irregular	NW–SE	EBA*		single				ceramic vessel (cattle bones in grave fill)	?		23–39 years	male?	maxilla PM2	0.71156	0.00001	104	–6.20	–	–
HU 24		12		pit	rectangular with rounded corners	NW–SE	EN	x	single					crouched on the left	4520±40 BP (deb-6869)	15–17 years	female?	maxilla r M1	0.71014	0.00001	131	–4.00	–	–
HU8		12		pit	rectangular with rounded corners	NW–SE	EN	x	single					crouched on the left	4520±40 BP (deb-6869)	15–17 years	female?	maxilla PM2(?)	0.70996	0.00001	100	–4.87	–	–
dentine																								
HU 5c		9		pit	oval	NNW–SSE(?)	EBA*		single		x		ceramic vessel (dog tooth in grave fill)	supine, legs in 'frog fork' position	4060±50 BP (deb-6871)	23–30 years	male	mandibula M3(?)	0.71035	0.00001	486	–	–	–
HU 6c		10		pit	?	W–E	EBA*		single				grinding stone (cattle and horse bones in grave fill)	crouched on the right	4350±40 BP (deb-6639)	44–50 years	male	maxilla M2	0.71027	0.00001	852	–	–	–
HU7c		11		pit	irregular	NW–SE	EBA*		single				ceramic vessel (cattle bones in grave fill)	?	–	23–39 years	male?	maxilla PM2	0.71047	0.00001	–	–	–	–
HU 8c		12		pit	rounded rectangular	NW–SE	EN	x	single					crouched on the left	4520±40 BP (deb-6869)	15–17 years	female	maxilla PM2(?)	0.71016	0.00001	602	–	–	–

Notes:

* assigned to Yamnaya culture

Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Kétegyháza-Kétegyházi tanyak																								
lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_c$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
HU15	3	7		pit	oval	W–E	EBA*	x	single	x (wood)			2 silver hair rings, necklace (43 pierced animal teeth), ochre piece, 3 sheep astragaloi	supine with crouched legs	4090 ± 35 (Poz-39103)	12–14 years	?	maxilla M1	0.70923	0.00001	84	–4.63	–	–
HU16	5/a	1		pit	rectangular with rounded corners?	W–E?	EBA*	x	single				(disturbed)	supine with crouched legs?	4130 ± 40 (Poz-39105)	30–35 years	male	maxilla M2	0.70916	0.00001	149	–5.33	–	–
HU17	6	1		pit	rectangular with rounded corners	W–E	EBA*	x	single		x	x (bones)	ochre piece	supine with crouched legs		35–40 years	female	maxilla M2	0.70987	0.00001	40	–4.54	–	–
HU18	6	3		pit	(not visible)	W–E	EBA*		single		x	x (bones and grave bottom)		supine with crouched legs	4180 ± 40 (Poz-39106)	30–35 years	male	maxilla M2	0.70916	0.00001	86	–5.82	–	–
dentine																								
HU 17c	6	1		pit	rectangular with rounded corners	W–E	EBA*	x	single		x	x (bones)	ochre piece	supine with crouched legs		35–40 years	female	maxilla M2	0.70924	0.00001	149	–	–	–
HU 18c	6	3		pit	(not visible)	W–E	EBA*		single		x	x (bones and grave bottom)		supine with crouched legs	4180 ± 40 (Poz-39106)	30–35 years	male	maxilla M2	0.70911	0.00001	519	–	–	–

Notes:
* assigned to Yamnaya culture
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Hungary (further sites)																									
lab ID	site	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_c$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
HU9	Balmazújváros-Árkusmajor-Kettőshalom		1		pit	rectangular	W–E	EBA*	? **	single	x (organic)	(clay-bench, grave bottom plastered)		ochre piece (small mug and animal bone above grave)	supine with crouched legs		35–40 years	male	maxilla M2	0.70953	0.00001	68	–	–	–
HU10	Debrecen-Basahalom		1		pit	rectangular? (2.11m × 1.2m)	W–E	EBA*	? **	single	x (wood)	x (covers skeleton?)		(horse bones and ceramcis, in burial mound)	probably supine position (destroyed)		30–35 years	male	maxilla M3	0.70949	0.00001	113	–	–	–
HU11_1	Debrecen-Dunahalom		1		pit	?	W–E?	EBA*	? **	single			x (beside skull, legs)	pebble stone	supine with crouched legs?		35–40 years	(male)	mandibula M3	0.71000	0.00001	74	–4.87	–	–
HU11_2	Debrecen-Dunahalom		1		pit	?	W–E?	EBA*	? **	single			x (beside skull, legs)	pebble stone	supine with crouched legs?		35–40 years	(male)	maxilla M2	0.71005	0.00001	119	–	–	–
HU12	Dévaványa-Barcéhalom		1		pit	rectangular (1.57m × 1m)	W–E	EBA*	no	single	postholes	x (organic spread)		ochre piece	supine with crouched legs		40–45 years	male	maxilla M3	0.70965	0.00001	140	–	–	–
HU13	Dévaványa-Csordajárás		2		pit	rectangular (rounded corners)	W–E	EBA*		single		x (bark spread)	x (skull)	ochre piece	supine with crouched legs		14–16 years	?	mandibula M2	0.70962	0.00001	76	–	–	–
HU14	Dévaványa-Csordajárás		3		pit	rectangular	W–E	EBA*		single		x		ochre piece	supine		0.5–1 years	?	maxilla M1	0.71011	0.00001	136	–	–	–
HU19	Püspökladány-Kincsesdomb		1		pit		W–E	EBA*	no	single		x (covers skeleton)			supine with crouched legs		30–35 years	male	maxilla M2	0.71010	0.00001	54	–	–	–
HU20	Sárrétudvari-Balázshalom				pit	rectangular? (1.9m × 1.3m)	W–E	EBA*	? **	single	x (blanket)	x	x (grave bottom)	ochre piece	supine with (slightly) crouched legs		25–30 years	female	maxilla M2	0.71003	0.00001	90	–	–	–
dentine																									
HU 9c	Balmazújváros-Árkusmajor-Kettőshalom		1		pit	rectangular	W–E	EBA*	? **	single	x (organic)	(clay-bench, grave bottom plastered)		ochre piece (small mug and animal bone above grave)	supine with crouched legs		35–40 years	male	maxilla M2	0.70991	0.00001	684	–	–	–
HU 12c	Dévaványa-Barcéhalom		1		pit	rectangular (1.57m × 1m)	W–E	EBA*	no	single	postholes	x (organic spread)		ochre piece	supine with crouched legs		40–45 years	male	maxilla M3	0.70983	0.00002	635	–	–	–
HU 14c	Dévaványa-Csordajárás		3		pit	rectangular	W–E	EBA*		single		x		ochre piece	supine		0.5–1 years	?	maxilla M1	0.71009	0.00001	625	–	–	–
HU20c	Sárrétudvari-Balázshalom				pit	rectangular? (1.9m × 1.3m)	W–E	EBA*	? **	single	x (blanket)	x	x (grave bottom)	ochre piece	supine with (slightly) crouched legs		25–30 years	female	maxilla M2	0.71042	0.00001	460	–	–	–

Notes:
* assigned to Yamnaya culture
** only burial described
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Kirovograd																								
lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_c$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
UK 7		5		pit	rectangular with platform (2.11m × 1.4m)	N–S	Yamnaya		single	construction of wooden frame and beams, postholes	x?	x	wagon parts incl. 4 disc wheels, fragments of decorated wooden cup, horse tooth, Unio seashell	supine with crouched legs	4142 ± 40 (KIA29934)	25–35 years	male	mandibula r M1	0.71010	0.00001	139	–	11.0	–19.1
UK 46		5		pit	rectangular with platform (2.11m × 1.4m)	N–S	Yamnaya		single	construction of wooden frame and beams, postholes	x?	x	wagon parts incl. 4 disc wheels, fragments of decorated wooden cup, horse tooth, Unio seashell	supine with crouched legs	4142 ± 40 (KIA29934)	25–35 years	male	mandibula l M2	0.71004	0.00001	131	–5.42	11.0	–19.1
UK 8		10	child	pit	rectangular (1.7m × 1.2m)	NE– SW	Yamnaya		double	postholes	x, 7 wooden beams		fluid ochre painting underneath child's skull, animal bones behind child's skull	crouched on the right	3470 ± 90 (Ki-13861)	8–11 years	–	mandibula r M1	0.71110	0.00001	193	–4.00	10.9 (bone) 13.0 (M1) 10.7 (M2)	–19.3 (bone) –19.3 (M1) –19.5 (M2)
UK 43		10	child	pit	rectangular (1.7m × 1.2m)	NE– SW	Yamnaya		double	postholes	x, 7 wooden beams		fluid ochre painting underneath child's skull, animal bones behind child's skull	crouched on the right	3470 ± 90 (Ki-13861)	8–11 years	–	mandibula l M2	0.71204	0.00001	200	–5,82	10.9 (bone) 13.0 (M1) 10.7 (M2)	–19.3 (bone) –19.3 (M1) –19.5 (M2)
UK 44		10	adult	pit	rectangular (1.7m × 1.2m)	SW– NE	Yamnaya		double	postholes	7 wooden beams			supine with crouched legs	3470 ± 90 (Ki-13861)	35–45 years	male	maxilla l M2	0.71139	0.00001	163	–5.21	–	–
UK 45		10	adult	pit	rectangular (1.7m × 1.2m)	SW– NE	Yamnaya		double	postholes	7 wooden beams			supine with crouched legs	3470 ± 90 (Ki-13861)	35–45 years	male	maxilla l M3	0.71106	0.00001	132	–	–	–
UK 48		13		catacomb	dromos, lateral oval grave chamber (2.45m × 1.6m)	SW– NE	Developed Catacomb culture		single	wood (in dromos)	x		ceramic vessel (decorated and coloured with ochre), stone axe, ochre piece	supine	3840 ± 90 (Ki-13863)	35–50 years	male	maxilla r M1	0.71061	0.00001	118	–4.72	11.0	–19.0
UK 49		13		catacomb	dromos, lateral oval grave chamber (2.45m × 1.6m)	SW– NE	Developed Catacomb culture		single	wood (in dromos)	x		ceramic vessel (decorated and coloured with ochre), stone axe, ochre piece	supine	3840 ± 90 (Ki-13863)	35–50 years	male	mandibula l M2	0.71068	0.00001	101	–4.71	11.0	–19.0

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Kirovograd cont.																								
lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_C$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
SU 11		14		pit	rectangular, rounded corners?	NE–SW	Yamnaya	x	single	7 oak beams (partly burned), plant remains above pit, remains of white colour, postholes	x, wooden beam	x	ochre piece, skull red ochre coloured	supine with crouched legs	4316 ± 33 (KIA29934)	30–35 years	male	maxilla M1	0.71079	0.00001	*	−4.66	12.4	−19.0
SU 10		16		pit	rectangular, rounded corners with platform (1.56m × 1.15m)	W–E	Yamnaya		single	5 wooden beams, postholes	x, and pillow, wooden beams	x	ceramic vessel, animal bones (sheep/goat), wooden mace, red ochre on skull and knees, in filling flint flake	crouched on the left (leathal head injury)	3930 ± 80 (Ki-13863)	45–50 years	male	maxilla M2	0.70992	0.00001	*	−7.17	10.1	−19.3
UK 41		20		pit	rectangular with platform (2.1m × 1.1m)	SW–NE	Yamnaya		single	wood, poss. logboat, postholes	x	x	2 disc wheels, ovoid ceramic vessel with V-bottom (decorated)	supine with crouched legs	4271 ± 34 (KIA29936)	45–55 years	male	maxilla r M2	0.71047	0.00001	139	−5.82	11.5 (bone) 11.3 (M2) 1.5 (M3)	−19.4 (bone) −19.4 (M2) −19.3 (M3)
UK 42		20		pit	rectangular with platform (2.1m × 1.1m)	SW–NE	Yamnaya		single	wood, poss. logboat, postholes	x	x	2 disc wheels, ovoid ceramic vessel with V-bottom (decorated)	supine with crouched legs	4271 ± 34 (KIA29936)	45–55 years	male	maxilla r M3	0.70953	0.00001	217	–	11.5 (bone) 11.3 (M2) 11.5 (M3)	−19.4 (bone) −19.4 (M2) −19.3 (M3)
UK 9		24		pit	rectangular with rounded corners (1.45m × 0.65m)	NW–SE	Yamnaya		single	wood and plant, postholes	x and pillow	x	ochre pieces	supine with crouched legs	4340 ± 80 (Ki-13864)	15–18 years	?	maxilla l M1	0.71083	0.00001	138	–	10.0	−18.0
UK 47		24		pit	rectangular with rounded corners (1.45m × 0.65m)	NW–SE	Yamnaya		single	wood and plant, postholes	x and pillow	x	ochre pieces	supine with crouched legs	4340 ± 80 (Ki-13864)	15–18 years	?	maxilla r M2	0.71076 (re-analysis: 0.71083)	0.00001 (re-analysis: 0.00001)	81	−5.61	10.0	−18.0

Notes:
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Kirovograd cont.																								
lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$87Sr/86Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_c$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
dentine																								
UK 42c		20		pit	rectangular with platform (2.1m × 1.1m)	SW–NE	Yamnaya		single	wood, poss. Logboat, postholes	x	x	2 disc wheels, ovoid ceramic vessel with V-bottom (decorated)	supine with crouched legs	4271 ± 34 (KIA29936)	45–55 years	male	maxilla r M3	0.71011	0.00005	484	–	–	–
UK 43c		10	child	pit	rectangular (1.7m × 1.2m)	NE–SW	Yamnaya		double	postholes	x, 7 wooden beams		fluid ochre painting underneath child's skull, animal bones behind child's skull	supine with crouched legs	3840 ± 90 (Ki-13863)	8–11 years	–	mandibula l M2	0.71041	0.00001	434	–	–	–
UK 47c		24		pit	rectangular with rounded corners (1.45m × 0.65m)	NW–SE	Yamnaya		single	wood and plant, postholes	x and pillow	x	ochre pieces	supine with crouched legs	4340 ± 80 (Ki-13864)	15–18 years	?	maxilla r M2	0.71022	0.00006	358	–	–	–
bone																								
UK B5		24		pit	rectangular with rounded corners (1.45m × 0.65m)	NW–SE	Yamnaya		single	wood and plant, postholes	x and pillow	x	ochre pieces	supine with crouched legs	4340 ± 80 (Ki-13864)	15–18 years	?	(humerus)	0.71021	0.00005	–	–	10.0	–18.0
UK B6		13		catacomb	dromos, lateral oval grave chamber (2.45m × 1.6m)	SW–NE	Developed Catacomb culture		single	wood (in dromos)	x		ceramic vessel (decorated and coloured with ochre), stone axe, piece of ochre	supine	3840 ± 90 (Ki-13863)	35–50 years	male	(tibia)	0.71017	0.00007	–	–	11.0	–19.0

Notes:
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_c$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
Nevskoe																								
OU 2	2	10		catacomb	oval (1.95m × 1.45m), rectangular entrance (2.2m × 1.43m)	S–N	Developed Catacomb culture*		double (with infant)			x	2 ceramic vessels, wooden cup	crouched on the right	3640 ± 70 (Ki-9521)	adult	?	maxilla M3	0.70924	0.00001	180	–6.00	–	–
OU 1	3	3		catacomb	oval (1.58m × 1.14m), oval entrance (1.55m × 1.2m)	S–N	Developed Catacomb culture*	x	single	x (wood)		x	ceramic vessel	crouched on the right		adult	?	maxilla M1	0.70904	0.00001	269	–5.81	–	–
OU 3	4	2		catacomb	oval (2.33m × 1.87m)	SE–NW	Developed Catacomb culture*		single			x	ceramic vessel, charcoal	crouched on the right		adult	?	mandibula M2	0.70911	0.00001	188	–5.54	–	–
OU 5	4	3		catacomb	oval (2.1m × 1.6m), rectangular entrance (1.77m × 1.5 m)	S–N	Developed Catacomb culture*		single		x	x	wooden cup, ochre piece, charcoal, bovine astragal	crouched on the right		adult	?	maxilla M3	0.70921	0.00001	168	–6.13	–	–
OU 4	5	9		catacomb	rectangular (2.2m × 2.2m), rectangular entrance (2.1m × 1.47m)	N–S	Developed Catacomb culture*		single	x			ceramic vessel, 2 wooden cups, animal bones, 2 ochre foot prints	crouched on the right		18 years	male	mandibula M1	0.70912	0.00001	155	–3.95	–	–
dentine																								
OU 2c	2	10		catacomb	oval (1.95m × 1.45m), rectangular entrance (2.2m × 1.43m)	S–N	Developed Catacomb culture*		double (with infant)	–		x	2 ceramic vessels, wooden cup	crouched on the right	3640 ± 70 (Ki-9521)	adult	?	maxilla M3	0.70946	0.00001	1933	–	–	–
OU 1c	3	3		catacomb	oval (1.58m × 1.14m), oval entrance (1.55m × 1.2m)	S–N	Developed Catacomb culture*	x	single	x (wood)		x	ceramic vessel	crouched on the right		adult	?	maxilla M1	0.70950	0.00001	1772	–	–	–
OU 3c	4	2		catacomb	oval (2.33m × 1.87m)	SE–NW	Developed Catacomb culture*		single	–		x	ceramic vessel, charcoal	crouched on the right		adult	?	mandibula M2	0.70951	0.00001	2049	–	–	–

Notes:
* Developed Catacomb culture (Kharkov-Voronezh)
Kurgans unpublished; list completed using notes of E. Kaiser (Lugansk, spring 2009).
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Peshtchanka																							
lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_C$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
UK 38	1	6		pit	oval (1.2m × 0.69m)	N–S	EN	x	single					supine with crouched legs	4940 ± 70 (Ki-15168)	45–50 years	male	mandibula l M1	0.71081	0.00002	488	–	12.0 (bone) 12.2 (M1) 12.3 (M3)	–18.8 (bone) –18.5 (M1) –18.8 (M3)
UK 33	1	6		pit	oval (1.2m × 0.69m)	N–S	EN	x	single					supine with crouched legs	4940 ± 70 (Ki-15168)	45–50 years	male	maxilla l M3	0.71036	0.00001	207	–5.71	12.0 (bone) 12.2 (M1) 12.3 (M3)	–18.8 (bone) –18.5 (M1) –18.8 (M3)
UK 39	1	7		pit	rectangular (2.2m × 1.1m)	NE–SW	EN	x	single		x	x	copper tubes (unknown number), flint object, ochre piece	supine with crouched legs	4880 ± 70 (Ki-15169)	30–40 years	male	maxilla r M2	0.71040	0.00001	282	–	–	–
UK 34	1	7		pit	rectangular (2.2m × 1.1m)	NE–SW	EN	x	single		x	x	copper tubes (unknown number), flint object, ochre piece	supine with crouched legs	4880 ± 70 (Ki-15169)	30–40 years	male	maxilla r M3	0.71069	0.00001	270	–4.92	–	–
UK 1	1	10		pit	rectangular with platform (3.0m × 2.5m)	S–N	Yamnaya		single	x	x		ceramic vessel, flint arrowhead, ochre piece, raptor claw	crouched on the right	3960 ± 60 (Ki-15171)	25–30 years	male	mandibula l M1	0.71018	0.00001	119	–4.99	13.0	–18.0
UK 40	1	10		pit	rectangular with platform (3.0m × 2.5m)	S–N	Yamnaya		single	x	x		ceramic vessel, flint arrowhead, ochre piece, raptor claw	crouched on the right	3960 ± 60 (Ki-15171)	25–30 years	male	maxilla l M3	0.71016	0.00001	153	–4.66	13.0	–18.0
UK 10	1	11		pit	rectangular with platform (2.75 m × 2.13m)	E–W	Yamnaya		single	x	x			crouched on the right	3970 ± 60 (Ki-15174)	11–13 years		mandibula l M1	0.71039	0.00001	173	–4.00	11.7	–18.0
UK 35	1	11		pit	rectangular with platform (2.75 m × 2.13m)	E–W	Yamnaya		single	x	x			crouched on the right	3970 ± 60 (Ki-15174)	11–13 years		mandibula l M2	0.71042	0.00001	201	–5.43	11.7	–18.0
UK 58	1	12		cata-comb	oval, rectangular entrance	SE–NW	Developed(?) Catacomb c.		single		x		(clay-modelled skull)	(destroyed)	3890 ± 60 (Ki-15173)	*	*	mandibula l M1	0.71021	0.00001	163	–4.18	–	–
UK 57	1	12		cata-comb	oval, rectangular entrance	SE–NW	Developed(?) Catacomb c.		single		x		(clay-modelled skull)	(destroyed)	3890 ± 60 (Ki-15173)	*	*	maxilla l M2	0.71010	0.00001	168	–5.79	–	–
UK 4	1	14		pit	rectangular (2.0m × 1.2m)	NE–SW	EN	x	single		x	x		supine	4890 ± 60 (Ki-15172)	35–40 years	male	mandibula l M1	0.70979	0.00001	209	–7.79	15.9 (M1) 14.3 (M2)	–17.2 (M1) –17.5 (M2)
UK 36	1	14		pit	rectangular (2.0m × 1.2m)	NE–SW	EN	x	single		x	x		supine	4890 ± 60 (Ki-15172)	35–40 years	male	maxilla l M2	0.70955	0.00001	222	–7.53	15.9 (M1) 14.3 (M2)	–17.2 (M1) –17.5 (M2)
UK 2	1	15		pit	rectangular (1.4m × 1.0m)	NE–SW	EN		single		x			crouched on the right	4630 ± 60 (Ki-15175)	30–40 years	female	maxilla l M1	0.71045	0.00001	120	–	10.0	–18.0

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Peshtchanka cont.																							
lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_c$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
UK 37	1	15		pit	rectangular (1.4m × 1.0m)	NE–SW	EN		single		x			crouched on the right	4630 ± 60 (Ki-15175)	30–40 years	female	maxilla l M2	0.71051	0.00001	224	–5.81	10.0	–18.0
dentine																								
UK 38c	1	6		pit	oval (1.2m × 0.69m)	N–S	EN	x	single					supine with crouched legs	4940 ± 70 (Ki-15168)	45–50 years	male	mandibula l M1	0.71070	0.00001	435	–	–	–
UK 33c	1	6		pit	oval (1.2m × 0.69m)	N–S	EN	x	single					supine with crouched legs	4940 ± 70 (Ki-15168)	45–50 years	male	maxilla l M3	0.71070	0.00001	400	–	–	–
UK 36c	1	14		pit	rectangular (2.0m × 1.2m)		EN	x	single		x	x		supine	4890 ± 60 (Ki-15172)	35–40 years	male	maxilla l M2	0.71043	0.00001	416	–	–	–
bone																								
UK B9	1	10		pit	rectangular with platform (3.0m × 2.5m)	S–N	Yamnaya		single	x	x		ceramic vessel, flint arrowhead, ochre piece, raptor claw	crouched on the right	3960 ± 60 (Ki-15171)	25–30 years	male	(femur)	0.71056	0.00001	–	–	13.0	–18.0
UK B10	1	11		pit	rectangular with platform (2.75 m × 2.13m)	E–W	Yamnaya		single	x	x			crouched on the right	3970 ± 60 (Ki-15174)	11–13 years		(femur)	0.71057	0.00001	–	–	11.7	–18.0

Notes:
* no data
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Shakhta Stepnaya																							
lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_C$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
UK 50	2	4		cata-comb	trapezoid (1.85m × 1.1m), round entrance	NE–SW	Developed Catacomb culture		single		x			supine		25–35 years	female	maxilla l M1	0.70978	0.00001	252	–4.63	–	–
UK 51	2	7		pit	rectangular (1.95m × 1.15m), with platform	SE–NW	Yamnaya		single	x		x		crouched on the right		35–40 (45) years	male	maxilla r M1	0.70994	0.00001	223	–5.78	–	–
UK 52	2	7		pit	rectangular (1.95m × 1.15m), with platform	SE–NW	Yamnaya		single	x		x		crouched on the right		35–40 (45) years	male	maxilla r M3	0.70997	0.00001	247	–	–	–
UK 55	4	10		cata-comb	oval (2.15m × 1.15m), round entrance	SE–NW	Developed Catacomb culture		double (female, baby)	x		x	3 ceramic vessels, object made of wood and leather	crouched on the right		20–25 years	female	maxilla l M1	0.70998	0.00001	230	–4.96	12.5	–18.0
UK 56	4	10		cata-comb	oval (2.15m × 1.15m), round entrance	SE–NW	Developed Catacomb culture		double (female, baby)	x		x	3 ceramic vessels, object made of wood and leather	crouched on the right		20–25 years	female	mandibula r M3	0.71003	0.00001	230	–5.24	12.5	–18.0
UK 53	4	11		pit	rectangular (2.1m × 1.6m), with platform	E–W	Yamnaya		single	x (wood, reed)		x	flint blade, leather object	crouched on the left		40–45 years	?	maxilla r M2	0.70996	0.00001	240	–5.38	11.8	–18.9
UK 54	4	11		pit	rectangular (2.1m × 1.6m), with platform	E–W	Yamnaya		single	x (wood, reed)		x	flint blade, leather object	crouched on the left		40–45 years	?	mandibula l M3	0.70995	0.00001	199	–4.00	11.8	–18.9
dentine																								
UK 50c	2	4		cata-comb	trapezoid (1.85m × 1.1m), round entrance	NE–SW	Developed Catacomb culture		single		x			supine		25–35 years	female	maxilla l M1	0.70980	0.00001	654	–	–	–
UK 55c	4	10		cata-comb	oval (2.15m × 1.15m), round entrance	SE–NW	Developed Catacomb culture		double (female, baby)	x		x	3 ceramic vessels, object made of wood and leather	crouched on the right		20–25 years	female	maxilla l M1	0.70994	0.00001	652	–	–	–
bone																								
UK B7	2	4		cata-comb	trapezoid (1.85m × 1.1m), round entrance	NE–SW	Developed Catacomb culture		single		x			supine		25–35 years	female	(femur?)	*	*	–	–	–	–
UK B8	4	10		cata-comb	oval (2.15m × 1.15m), round entrance	SE–NW	Developed Catacomb culture		double (female, baby)	x		x	3 ceramic vessel, object made of wood and leather	crouched on the right		20–25 years	female	(humerus)	0.70991	0.00001	–	–	12.5	–18.0

Notes:
* no data
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Vinogradnoe																								
lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_C$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
UK 30	3	15		pit	oval*	E–W	EN	x	single		?	?	flint object	supine with crouched legs	5230 ± 60 (Ki-14726)	35–40 years	male	mandibula r M2	0.70990	0.00001	456	–5.51	13.0	–19.0
UK 27	3	25		pit	rectangular with platform*	NE–SW	Yamnaya		single	x (wood)	x	?	4 wooden wheels on platform, bone, bronze	crouched on the right	4020 ± 70 (Ki-14660), 3765 ± 70 (Ki-9399), 3970 ± 70 (Ki-9413)	~ 25 years	male	maxilla r M2	0.70994	0.00001	251	–4.00	12.0	–18.0
UK 31	3	25		pit	rectangular with platform*	NE–SW	Yamnaya		single	x (wood)	x	?	4 wooden wheels on platform, bone, bronze	crouched on the right	4020 ± 70 (Ki-14660), 3765 ± 70 (Ki-9399), 3970 ± 70 (Ki-9413)	~ 25 years	male	mandibula r M3	0.70984	0.00001	244	–6.35	12.0	–18.0
UK 32	3	36		cata-comb	oval*	E–W	Developed Catacomb culture		double		x	?	ceramic vessels	stretched on the right	4020 ± 70 (Ki-9390), 4060 ± 50 (Ki-15167)	50–55 years	female??	mandibula r M1	0.70985	0.00001	814	–4.42	–	–
UK 29	3	36		cata-comb	oval*	E–W	Developed Catacomb culture		double		x	?	ceramic vessels	stretched on the right	4020 ± 70 (Ki-9390), 4060 ± 50 (Ki-15167)	50–55 years	female??	mandibula r M2	0.70986	0.00001	977	–4.00	–	–
UK 3	24	8	1	pit	rectangular with platform (2.5m × 1.7m)	SE–NW	Yamnaya		double	x (wood)	x (bark)	x	grinding stone, As-Cu dagger with case, fragment of a bone pin, 5 astra-galoi	crouched on the right	4146 ± 40 (Bln-4688)	23–25 years	male?	maxilla M1	0.70977	0.00001	315	–	–	–
UK 22	24	8	1	pit	rectangular with platform (2.5m × 1.7m)	SE–NW	Yamnaya		double	x (wood)	x (bark)	x	grinding stone, As-Cu dagger with case, fragment of a bone pin, 5 astra-galoi	crouched on the right	4146 ± 40 (Bln-4688)	23–25 years	male?	maxilla l M2	0.70982	0.00001	292	–5,01	–	–
UK 11	24	8	2	pit	rectangular with platform (2.5m × 1.7m)	SE–NW	Yamnaya		double	x (wood)	x (bark)	x	grinding stone, As-Cu dagger with case, fragment of a bone pin, 5 astra-galoi	crouched on the right	4146 ± 40 (Bln-4688)	11–14 years		maxilla r M1	0.70961	0.00001	346	–4.00	12,4	–18.0
UK 12	24	8	2	pit	rectangular with platform (2.5m × 1.7m)	SE–NW	Yamnaya		double	x (wood)	x (bark)	x	grinding stone, As-Cu dagger with case, fragment of a bone pin, 5 astra-galoi	crouched on the right	4146 ± 40 (Bln-4688)	11–14 years		mandibula r M2	0.70960	0.00001	284	–4.67	12,4	–18.0

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Vinogradnoe cont.																								
lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_C$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
UK 28	24	15	1	catacomb	rectangular (3.55m × 2.4m), quadratic entrance pit	NW–SE	Early Catacomb culture		double	x (wood)	x			1 crouched on the left, 1 bone pile	4113 ± 42 (Bln-4696), 3900 ± 60 (Ki-15201)	(30)/ 35–45 years	male	mandibula r M3	0.70977	0.00001	307	–6.59	13.0	–18.0
UK 15	24	15	2	catacomb	rectangular (3.55m × 2.4m), quadratic entrance pit	NW–SE	Early Catacomb culture		double	x (wood)	x			1 crouched on the left, 1 bone pile	4113 ± 42 (Bln-4696), 3900 ± 60 (Ki-15201)	30–45 years	female	maxilla l M2	0.70956	0.00001	235	–	13.0	–17.0
UK 23	24	15	2	catacomb	rectangular (3.55m × 2.4m), quadratic entrance pit	NW–SE	Early Catacomb culture		double	x (wood)	x			1 crouched on the left, 1 bone pile	4113 ± 42 (Bln-4696), 3900 ± 60 (Ki-15201)	30–45 years	female	maxilla l M3	0.70949	0.00001	327	–5.00	13.0	–17.0
UK 20	24	17	1	catacomb	oval (1.65m × 1.23m), entrance not preserved		Developed Catacomb culture		double					1 supine, 1 bone pile	3970 ± 60 (Ki-15205)	45–55 years	male	mandibula r M1	0.70997	0.00001	96	–4.00	12.1	–18.0
UK 18	24	17	1	catacomb	oval (1.65m × 1.23m), entrance not preserved		Developed Catacomb culture		double					1 supine, 1 bone pile	3970 ± 60 (Ki-15205)	45–55 years	male	mandibula r M2	0.70980	0.00001	191	–5.96	12.1	–18.0
UK 13	24	19	1	catacomb	rectangular (2.2m × 1.5m), rectangular entrance pit	SO–NW	Early Catacomb culture		double		x	x		supine with crouched legs (2, 2nd individual = child)	4280 ± 70 (Ki-9401)	25–35 years	male	mandibula l M3	0.71022	0.00001	137	–5.13	13.0	–18.0
UK 6	24	22		catacomb	rectangular (2.37m × 1.55m), rectangular entrance pit	SW–NO	Early Catacomb culture		single	x (wood)	x and pillow	x	bow?, As-Cu dagger, As-Cu awl with case, stone axe, 2 flint arrowhead, silver pendant	crouched on the right	4131 ± 39 (Bln-4692)	17–20 years	male	maxilla r M1	0.70982	0.00001	225	–3.62	12.0	–18.0

Notes:
* according to drawing, no measurements given
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Vinogradnoe cont.																							
lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_c$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
UK 16	24	22		catacomb	rectangular, 2.37m × 1.55m, rectangular entrance pit	SW–NO	Early Catacomb culture		single	x (wood)	x and pillow	x	bow?, As-Cu dagger, As-Cu awl with case, stone axe, 2 flint arrowhead, silver pendant	crouched on the right	4131 ± 39 (Bln-4692)	17–20 years	male	maxilla l M3	0.70986	0.00001	224	–5.08	12.0	–18.0
UK 17	24	26		catacomb	oval (2m × 1.7m), oval entrance	SE–NW	Developed Catacomb culture		single		x	x	2 wooden objects	crouched on the right		30–40 years	male?	maxilla l M2	0.70975	0.00001	322	–	–	–
UK 25	24	26		catacomb	oval (2m × 1.7m), oval entrance	SE–NW	Developed Catacomb culture		single		x	x	2 wooden objects	crouched on the right		30–40 years	male?	maxilla r M3	0.70961	0.00001	310	–6.17	–	–
UK 14	24	30		pit	oval (1.92m × 1.08m)	NE–SW	EN	x	single			x, chalk	–	crouched on the right	4980 ± 70 (Ki-14657), 3810 ± 60 (Ki-15206)	40–50 years	male	maxilla l M3	0.71013	0.00001	167	–4.00	–	–
UK 21	24	31		pit	rectangular (1.93m × 1.54m)	E–W	Yamnaya		single	x (wood)	x	x	–	crouched on the right	4226 ± 40 (Bln-4694), 4090 ± 60 (Ki-15202)	30–45 years	male	mandibula l M3	0.70988	0.00001	336	–5.45	12.4	–18.0
UK 5	24	32		catacomb	oval (2.15m × 1.15m), oval entrance	SE–NW	Developed Catacomb culture		single					supine	3940 ± 60 (Ki-15204)	40–45/(50) years	male	mandibula r M1	0.70989	0.00001	352	–4.49	12.0	–19.2
UK 26	24	32		catacomb	oval (2.15m × 1.15m), oval entrance	SE–NW	Developed Catacomb culture		single					supine	3940 ± 60 (Ki-15204)	40–45/(50) years	male	mandibula r M2	0.70983	0.00001	227	–	12.0	–19.2
UK 24	24	34	1	catacomb	rectangular, oval entrance*	SE–NW	Early Catacomb culture		double	?	?	x	2 wooden wheels in entrance area, 2 wooden objects in grave chamber	crouched on the right	4160 ± 19 (IV-3133), 3880 ± 60 (Ki-15203)	30–35 years	female	maxilla l M3	0.70982	0.00001	379	–5.99	12.0	–17.0
UK 19	24	34	2	catacomb	rectangular, oval entrance*	SE–NW	Early Catacomb culture		double	?	?	x	2 wooden wheels in entrance area, 2 wooden objects in grave chamber	crouched on the left	4160 ± 19 (IV-3133), 3880 ± 60 (Ki-15203)	30–35 years	male	maxilla l M3	0.70969	0.00001	129	–5.90	14.0	–18.0

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Vinogradnoe cont.																							
lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_C$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
dentine																								
UK 22c	24	8	1	pit	rectangular with platform (2.5m × 1.7m)	SE–NW	Yamnaya		double	x (wood)	x (bark)	x	grinding stone, As-Cu dagger with case, fragment of a bone pin, 5 astragaloi	crouched on the right	4146 ± 40 (Bln-4688)	23–25 years	male?	maxilla l M2	0.70978	0.00001	1128	–	–	–
UK 13c	24	19	1	catacomb	rectangular (2.2m × 1.5m), rectangular entrance pit	SE–NW	Early Catacomb culture		double		x	x		supine with crouched legs (2, adult + child)	4280 ± 70 (Ki-9401)	25–35 years	male	mandibula l M3	0.70984	0.00001	431	–	–	–
UK 25c	24	26		catacomb	oval (2m × 1.7m), oval entrance	SE–NW	Developed Catacomb culture		single		x	x	2 wooden objects	crouched on the right		30–40 years	male?	maxilla r M3	0.70976	0.00001	764	–	–	–
bone																								
UK B1	3	25		pit	rectangular with platform*	NE–SW	Yamnaya		single	x (wood)	x	?	4 wooden wheels on platform	crouched on the right	4020 ± 70 (Ki-14660), 3765 ± 70 (Ki-9399), 3970 ± 70 (Ki-9413)	~ 25 years	male	(femur)	0.70986	0.00001	–	–	12.0	–18.0
UK B2	3	15		pit	oval*	E–W	EN	x	single		?	?	flint object	crouched on the back		35–40 years	male	(femur)	0.70989	0.00001	–	–	13.0	–19.0
UK B3	24	8	2	pit	rectangular with platform (2.5m × 1.7m)	SE–NW	Yamnaya		double	x (wood)	x (bark)	x	grinding stone, As-Cu dagger with case, fragment of a bone pin, 5 astragaloi	crouched on the right	4146 ± 40 (Bln-4688)	11–14 years		(humerus)	0.70974	0.00001	–	–	12.4	–18.0
UK B4	24	17	1	catacomb	oval (1.65m × 1.23m), entrance not preserved		Developed Catacomb culture		double					1 supine, 1 bone pile	3970 ± 60 (Ki-15205)	45–55 years	male	(tibia)	0.70985	0.00001	–	–	12.1	–18.0

Notes:
* according to drawing, no measurements given
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_c$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
Kalinovka I																								
Wo 6	1	3		pit*	rectangular (2.57m × 1.70m)	E–W	Poltavka culture*	x	single	x (wood)	x (wood/ bark)	x	big ceramic fragment (coal pan)	?	4050 ± 70 (GIN11289)	>= 55 years	male	mandibula l M1	0.70862	0.00001	228	–6.86	–	–
Wo 4	1	4		?	?	NE–SW	Poltavka culture*		single			x	deposition of sheep bone and fox mandible	crouched on the left		50–55 years	male	mandibula l M1	0.70892	0.00001	215	–5.86	–	–
Wo 5	1	6		pit*	rectangular (1.40m × 0.90m)	E–W	Poltavka culture*		single		x	x	ceramic vessel, ceramic fragments, CU-AS awl, CU-AS sheets, grinding stone, 4 shells, 4 astragaloi, ochre piece, charcoal	crouched on the left		60–70 years	female	maxilla l M3	0.70868	0.00001	184	–7.40	–	–
dentine																								
Wo 6c	1	3		pit*	rectangular (2.57m × 1.70m)	E–W	Poltavka culture*	x	single	x (wood)	x (wood/ bark)	x	big ceramic fragment (coal pan)	?	4050 ± 70 (GIN11289)	>= 55 years	male	mandibula l M1	0.70908	0.00001	1053	–	–	–
Wo 4c	1	4		?	?	NE–SW	Poltavka culture*		single			x	deposition of sheep bone and fox mandible	crouched on the left		50–55 years	male	mandibula l M1	0.70902	0.00001	782	–	–	–

Notes:

* Poltavka culture in the Volga region comprises features of both Yamnaya and Catacomb culture

Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Politotdel'skoe																							
lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_C$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
Wo 2	2	2		pit	oval (top 1.74m × 1.07m, bottom 1.58m × 0.90m)	E–W	Poltavka culture*		single	x (wood)	x	x	ceramic vessel	crouched on the right (skull deformed)		40–45 years	male	mandibula r M2	0.70916	0.00001	196	–4.80	–	–
Wo 3	2	3		catacomb	oval (1.80m × 1.16m), oval entrance (1.82m × 1.16m)	NW–SE	Poltavka culture*		single				2 ceramic vessels, animal bones	crouched on the right (skull deformed)		young adult (17–20 years)		mandibula l M2	0.70881	0.00001	193	–6.07	–	–
Wo 1	4	6		catacomb	rectangular (1.35m × 0.54m), oval entrance (1.47m × 0.83m, sealed with clay)	NE–SW	Poltavka culture*	x?	single			x	Cu-As spiral ring, animal bones	crouched on the left (skull deformed)		infant		maxilla l M1	0.70902	0.00001	228	–5.58	–	–
dentine																								
Wo 2c	2	2		pit	oval (top 1.74m × 1.07m), bottom (1.58m × 0.90m)	E–W	Poltavka culture*		single	x (wood)	x	x	ceramic vessel	crouched on the right (skull deformed)		40–45 years	male	mandibula r M2	0.70928	0.00001	990	–	–	–
Wo 3c	2	3		catacomb	oval (1.80m × 1.16m), oval entrance (1.82m × 1.16m)	NW–SE	Poltavka culture*		single				2 ceramic vessels, animal bones	crouched on the right (skull deformed)		young adult (17–20 years)		mandibula l M2	0.70929	0.00001	1068	–	–	–

Notes:
* Poltavka culture in the Volga region comprises features of both Yamnaya and Catacomb culture
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Nikolaevka III																								
lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_C$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
Wo 10	1	2		pit	rectangular (1.85m × 1.20m)	E–W	Poltavka culture*		single	x (wood)	x	x	animal bones	supine (destroyed)		old adult	female?	maxilla M2	0.70873	0.00001	204	–6.66	–	–
Wo 13	1	3		pit	rectangular (1.80m × 1.13m)	E–W	Poltavka culture*		single		x		charcoal	supine with crouched legs		40–55 years	male	mandibula l M2	0.70886	0.00001	206	–6.35	–	–
Wo 9	2	1	1	pit	quadratic (2.30m × 1.80–2.20m)	NE–SW	Poltavka culture*	x	double		x (pillow)	x	sheep bones	supine with crouched legs		juvenile (12 years)		mandibula l M2	0.70887	0.00001	162	–6.79	–	–
Wo 17	2	1	2	pit	quadratic (2.30m × 1.80–2.20m)	NE–SW	Poltavka culture*	x	double		x (pillow)	x	sheep bones	supine with crouched legs		45 years	male	maxilla l M1	0.70934	0.00001	319	–6.33	–	–
Wo 18	2	1	2	pit	quadratic (2.30m × 1.80–2.20m)	NE–SW	Poltavka culture*	x	double		x (pillow)	x	sheep bones	supine with crouched legs		45 years	male	mandibula M3	0.708736	0.00001	122	–7.21	–	–
Wo 8	3	1	1	pit	rectangular (1.47m × 1.08–1.29m)	E–W	Poltavka culture*	x	double		x (clay and organic, pillow)		ceramic vessel, 2 copper (Cu-As) spectacle pendants, copper (Cu-As) tube, 12 bone tubes, 7 bird bone tubes	crouched on the right		7–8 years	male?	mandibula l M1	0.70841	0.00001	212	–5.77	–	–
Wo 11	3	1	2	pit	rectangular (1.75m × 1.15–1.29m)	E–W	Poltavka culture*	x	double					crouched on the right		~ 40 years	male	mandibula r M1	0.70894	0.00001	135	–6.87	–	–
Wo 12	3	4		pit	rectangular (1.50m × 0.98m)	N–S	Poltavka culture*		single					supine with crouched legs? (destroyed)		40–50 years	male	maxilla l M1	0.70881	0.00001	225	–7.01	–	–
Wo 7	5	1		pit	rectangular (1.31m × 0.55–0.88m)	N–S	Poltavka culture*	x	single			x		crouched on the left		40–55 years	male	mandibula r M1	0.70901	0.00001	159	–6.17	–	–
dentine																								
Wo 13c	1	3		pit	rectangular (1.80m × 1.13m)	E–W	Poltavka culture*		single		x		charcoal	supine with crouched legs		40–55 years	male	mandibula l M2	0.70964	0.00001	1047	–	–	–
Wo 17c	2	1	2	pit	quadratic (2.30m × 1.80–2.20m)	NE–SW	Poltavka culture*	x	double		x (pillow)	x	sheep bones	supine with crouched legs		45 years	male	maxilla l M1	0.70969	0.00001	919	–	–	–
Wo 8c	3	1	1	pit	rectangular (1.47m × 1.08–1.29m)	E–W	Poltavka culture*	x	double		x (clay and organic, pillow)		ceramic vessel, 2 copper (Cu-As) spectacle pendants, copper (Cu-As) tube, 12 bone tubes, 7 bird bone tubes	crouched on the right		7–8 years	male?	mandibula l M1	0.70957	0.00001	1298	–	–	–
Wo 7c	5	1		pit	rectangular (1.31m × 0.55–0.88m)	N–S	Poltavka culture*	x	single			x		crouched on the left		40–55 years	male	mandibula r M1	0.70947	0.00001	597	–	–	–

Notes:

* Poltavka culture in the Volga region comprises features of both Yamnaya and Catacomb culture

Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_C$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
Olennii																								
OL 1	1	21	b	pit	rectangular (top 3.8m × 2.4m, bottom 1.5m × 0.6m)	W–E	Novotitarovskaya culture		double	x (wood, bast)	x	x	ceramic vessel (censer), fragment of ceramic vessel, 2 copper? spiral rings, set of bone objects, animal bones	supine? (partly destroyed)		2 years		mandibula m2 *	0.70950	0.00001	182	–5.64	–	–
OL 2	2	25	b	pit	rectangular (top 3.9m × 3.2m, bottom 1.6m × 0.65m)	W–E	Novotitarovskaya culture		double	x (wood)	x	x	wagon near the grave, fragment of a ceramic vessel like a censer, 2 silver spiral rings, bone beads	supine with crouched legs	4112 ± 28 (OxA-22953)	4–5 years		mandibula m2 *	0.70981	0.00001	312	–5.33	11.0	–19.5
OL 3	2	26		pit	rectangular (top 3.8m × 2.8m, bottom 1.4m × 0.9m)	W–E	Novotitarovskaya culture		single	x (wood, bast)	x	x	ceramic vessel, animal bones	crouched, partly sitting position		20–25 years	female	mandibula M3	0.70950	0.00001	110	–5.40	–	–
OL 4	2	35	a	pit	rectangular (top 2.1m × 1.7m, bottom 1.2m × 1.0m)	W–E	Novotitarovskaya culture		double	x (wood)	x	x	fragment of ceramic vessel, bone beads, sheep/goat skull	crouched on the right	4153 ± 29 (OxA-22954)	4–5 years		mandibula m2 *	0.70951	0.00001	194	–4.87	13,1	–19.0
OL 5	2	35	b	pit	rectangular pit (top 2.1m × 1.7m, bottom 1.2m × 1.0m)	W–E	Novotitarovskaya culture		double	x (wood)	x	x	fragment of ceramic vessel, bone beads, sheep/goat skull	crouched on the right		3–5 years		mandibula m2 *	0.70948	0.00001	240	–4.93	–	–
OL 6	3	3		pit	rectangular (> 1.4m × 1.0m ?)	W–E	Novotitarovskaya culture		single	x (wood)	x	x		crouched on the right? (destroyed)		25–35 years	male?	mandibula M2	0.70948	0.00001	195	–4.00	–	–
OL 7	3	14	a	pit	rectangular (1.5m × 1.0m)	SW–NE	Novotitarovskaya culture		double		x	x	ceramic vessel, bone bead	crouched on the right	4287 ± 30 (OxA-23079)	25–35 years	?	canine	0.70945	0.00001	177	–4.66	12.0	–18.0
dentine																								
OL 2c	2	25	b	pit	rectangular (top 3.9m × 3.2m, bottom 1.6m × 0.65m)	W–E	Novotitarovskaya culture		double	x (wood)	x	x	wagon near the grave, fragment of a ceramic vessel like a censer, 2 silver spiral rings, bone beads	supine with crouched legs	4112 ± 28 (OxA-22953)	4–5 years		mandibula m2 *	0.70947	0.00001	3077	–	–	–
OL 4c	2	35	a	pit	rectangular (top 2.1m × 1.7m, bottom 1.2m × 1.0m)	W–E	Novotitarovskaya culture		double	x (wood)	x	x	fragment of ceramic vessel, bone beads, sheep/goat skull	crouched on the right	4153 ± 29 (OxA-22954)	4–5 years		mandibula m2 *	0.70945	0.00001	1394	–	–	–
OL 6c	3	3		pit	rectangular (> 1.4m × 1.0m ?)	W–E	Novotitarovskaya culture		single	x (wood)	x	x		crouched on the right? (destroyed)		25–35 years	male?	mandibula M2	0.70943	0.00001	824	–	–	–

Notes:
* m = deciduous molar
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_C$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
Podlesnyi																								
Wo 15	3	3		pit	rectangular (1.90m × 1.20m)	E–W	Poltavka culture*	x	single	x (wood)		x	– (offering pit above grave: chalk, bark?, wood, ceramic vessel)	supine with crouched legs	4260 ± 50 (GIN13206), 4290 ± 40 (GIN13207), 4390 ± 50 (GIN13208)	45–55 years	male	mandibula r M1	0.70972	0.00001	193	–5.29	–	–
Wo 14	3	5		pit	rectangular (1.70m × 1.10m)	NW–SE	Poltavka culture*		single			x		supine with crouched legs		15–16 years	female	maxilla r M1	0.70879	0.00001	282	–6.30	–	–
Wo 16	3	6		pit	rectangular (1.90m × 1.20m)	?	Poltavka culture*		single	x (wood)		x	ceramic vessel	crouched on the right	4190 ± 40 (GIN13209), 4110 ± 50 (GIN13210)	25–30 years	male	mandibula l M1	0.70827	0.00001	1010	–6.53	–	–
Wo 19	3	6		pit	rectangular (1.90m × 1.20m)	?	Poltavka culture*		single	x (wood)		x	ceramic vessel	crouched on the right	4190 ± 40 (GIN13209), 4110 ± 50 (GIN13210)	25–30 years	male	maxilla l M3	0.70863	0.000017	165	–8.11	–	–
dentine																								
Wo 15c	3	3		pit	rectangular (1.90m × 1.20m)	E–W	Poltavka culture*	x	single	x (wood)		x	– (offering pit above grave: chalk, bark?, wood, ceramic vessel)	supine with crouched legs	4260 ± 50 (GIN13206), 4290 ± 40 (GIN13207), 4390 ± 50 (GIN13208)	45–55 years	male	mandibula r M1	0.70934	0.00001	–	–	–	–
Wo 14c	3	5		pit	rectangular (1.70m × 1.10m)	NW–SE	Poltavka culture*		single			x		supine with crouched legs		15–16 years	female	maxilla r M1	0.70905	0.00001	–	–	–	–
Wo 16c	3	6		pit	rectangular (1.90m × 1.20m)	?	Poltavka culture*		single	x (wood)		x	ceramic vessel	crouched on the right	4190 ± 40 (GIN13209), 4110 ± 50 (GIN13210)	25–30 years	male	mandibula l M1	0.70903	0.00001	1074	–	–	–

Notes:
* Poltavka culture in the Volga region comprises features of both Yamnaya and Catacomb culture
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

lab ID	kurgan	grave	individual	tomb type	grave shape	orientation	relative date	primary burial	burial	cover	organic mat	ochre spread	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_c$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
Sukhaya Termista II																								
RE 6	1	2		catacomb	oval, rectangular entrance, dromos E–W	SE–NW	Early Catacomb culture	x	single			x (on skull, legs)		supine	4050 ± 70 (IGAN-3814)	adult	(male)?	mandibula M1	0.70910	0.00001	150	−4.00	–	–
RE 5	1	2		catacomb	oval, rectangular entrance, dromos E–W	SE–NW	Early Catacomb culture	x	single			x (on skull, legs)		supine	4050 ± 70 (IGAN-3814)	adult	(male)?	mandibula M3	0.70900	0.00001	143	−5.65	–	–
RE 1	1	3		catacomb	oval, rectangular entrance, dromos E–W	SSE–NNW	Early Catacomb culture		double (with neonate)			x (on skull)	10 bronze beads, 4 bronze pendants, piece of red ochre	supine, legs on the left		18–20	female	mandibula M1	0.70918	0.00001	145	−5.54	–	–
RE 2	1	3		catacomb	oval, rectangular entrance, dromos E–W	SSE–NNW	Early Catacomb culture		double (with neonate)			x (on skull)	10 bronze beads, 4 bronze pendants, piece of red ochre	supine, legs on the left		18–20	female	mandibula M3	0.70916	0.00001	191	−6.47	–	–
RE 7	1	5		catacomb	oval, rectangular entrance, dromos	E–W	Early Catacomb culture		single				censer*	supine		adolescent?		mandibula M1	0.70892	0.00001	216	−5.00	–	–
RE 8	1	5		catacomb	oval, rectangular entrance, dromos	E–W	Early Catacomb culture		single				censer*	supine		adolescent?		mandibula M2	0.70914	0.00001	151	−5.33	–	–
RE 3	3	20		catacomb	oval, rectangular entrance	SE–NW	Early Catacomb culture		single		x	x (on legs)		supine	4153 ± 28 (OxA-23084)	40–45	male	mandibula M1	0.70889	0.00001	186	−5.72	–	–
RE 4	3	20		catacomb	oval, rectangular entrance	SE–NW	Early Catacomb culture		single		x	x (on legs)		supine	4153 ± 28 (OxA-23084)	40–45	male	mandibula M3	0.70915	0.00001	199	−5.55	–	–
bone																								
RE B1	3	20		catacomb	oval, rectangular entrance	SE–NW	Early Catacomb culture		single		x	x (on legs)		supine	4153 ± 28 (OxA-23084)	40–45	male	(femur)	0.70916	0.00001	–	–	–	–
RE B2	1	3		catacomb	oval, rectangular entrance, dromos E–W	SSE–NNW	Early Catacomb culture		double (with neonate)			x (on skull)	10 bronze beads, 4 bronze pendants, piece of red ochre	supine, legs on the left		18–20	female	(femur)	0.70917	0.00001	–	–	–	–
RE B3	1	2		catacomb	oval, rectangular entrance, dromos E–W	SE–NW	Early Catacomb culture	x	single			x (on skull, legs)		supine	4050 ± 70 (IGAN-3814)	adult	(male)?	(femur)	0.70914	0.00001	–	–	–	–

Notes:

* censer (in Russian kurilnitsa) = ceremonial clay vessels where fire (incl. steppe plants and flowers)

Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Alexandropol'																				
lab ID	kurgan	grave	individual	tomb type	orientation	relative date	primary burial	burial	burial objects	position of skeleton	absolute date	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_C$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
AL 1	5	1		pit*	W–E	Scythian		?	no individual burial objects (remains of symposium)	supine	3rd quarter 4th c. BC**	20–30 years	male	maxilla M3	0.71004	0.00001	257	–6.07	–	–
AL 2	12	4		pit*	W–E	Scythian		?	no individual burial objects (remains of symposium)	supine	3rd quarter 4th c. BC**	25–30 years	male	mandibula M1	0.70991	0.00001	145	–4.58	–	–
AL 3	15	6		pit*	SW–NE	Scythian		?	no individual burial objects (remains of symposium)	supine	3rd quarter 4th c. BC**	17–22 years	male	mandibula M1	0.71004	0.00001	111	–6.15	–	–
AL 4	15	8		pit*	SW–NE	Scythian		?	no individual burial objects (remains of symposium)	supine	3rd quarter 4th c. BC**	45–55 years	male	maxilla M3	0.70962	0.00001	304	–6.67	–	–
AL 5	10	3		pit*	W–E	Scythian		?	no individual burial objects (remains of symposium)	supine	3rd quarter 4th c. BC**	25–35 years	male	maxilla M3	0.70979	0.00001	–	–5.38	–	–
dentine																				
AL 1c	5	1		pit*	W–E	Scythian		?	no individual burial objects (remains of symposium)	supine	3rd quarter 4th c. BC**	20–30 years	male	maxilla M3	0.71020	0.00001	412	–	–	–
AL 2c	12	4		pit*	W–E	Scythian		?	no individual burial objects (remains of symposium)	supine	3rd quarter 4th c. BC**	25–30 years	male	mandibula M1	0.71022	0.00001	602	–	–	–
AL 3c	15	6		pit*	SW–NE	Scythian		?	no individual burial objects (remains of symposium)	supine	3rd quarter 4th c. BC**	17–22 years	male	mandibula M1	0.71017	0.00001	573	–	–	–

Notes:
* looted, evidences for cover (wood, stone, amphorae)
** dating of amphorae
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

lab ID	kurgan	grave	individual	tomb type	orientation	relative date	primary burial	burial	burial objects	position of skeleton	absolute date	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_C$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
Babina Mogila																				
O1		burial chamber 1	'servant' (in dromos)	rectangular (4.5m × 3.1m, looted), only 1 skeleton preserved (in dromos)	(not visible)	Scythian		single	bronze wagon fitting, fragments of > 91 vessels (including Greek amphorae), further objects in main burial (not preserved)	(not visible)	4th c. BC*	old adult	male	maxilla M1	0.70994	0.00001	164	–5.22	–	–
O3		burial chamber 3	central burial	trapezoid (4.35m × 2.35m), rectangular entrance (2.7m × 1.6m), (destroyed)	(not visible)	Scythian	?	?	x (destroyed)	(not visible)	4th c. BC*	13–15 years		maxilla M1	0.70950	0.00001	168	–6.41	–	–
dentine																				
O 1c		burial chamber 1	'servant' (in dromos)	rectangular (4.5m × 3.1m, looted), only 1 skeleton preserved (in dromos)	(not visible)	Scythian		single	bronze wagon fitting, fragments of > 91 vessels (including Greek amphorae), further objects in main burial (not preserved)	(not visible)	4th c. BC*	old adult	male	maxilla M1	0.70993	0.00001	–	–	–	–
O 3c		burial chamber 3	central burial	trapezoid (4.35m × 2.35m), rectangular entrance (2.7m × 1.6m), (destroyed)	(not visible)	Scythian	?	?	x (destroyed)	(not visible)	4th c. BC*	13–15 years		maxilla M1	0.70993	0.00001	1071	–	–	–

Notes:
* dating of amphorae
** amphora stamp
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Drana Kokhta																				
lab ID	**kurgan**	**grave**	**individual**	**tomb type**	**orientation**	**relative date**	**primary burial**	**burial**	**burial objects**	**position of skeleton**	**absolute date**	**age at death**	**sex**	**sampled tooth**	**$^{87}Sr/^{86}Sr$**	**2 S.E.**	**Sr concentration (ppm)**	**$\delta^{18}O_c$ (‰ vs. V-PDB)**	**$\delta^{15}N$ (bone, ‰ vs. AIR)**	**$\delta^{13}C$ (bone, ‰ vs. V-PDB)**
O4		niche 5		niche	W–E	Scythian		single	bronze earring, bangle and tongs made of iron, bead necklace	supine		14–15 years	female (archaeological)	maxilla M3	0.71072	0.00001	121	−5.28	–	–
O16		central burial	male adult	complex catacomb with dromoi	? (destroyed)	Scythian	x	6 individuals (3 adults, 3 children)	2 horse burials with equipment	? (destroyed)		50–55 years	male	mandibula M3	0.70984	0.00001	119	−5.39	–	–
dentine																				
O4c		niche 5		niche	W–E	Scythian		single	bronze earring, bangle and tongs made of iron, bead necklace	supine		14–15 years	female (archaeological)	maxilla M3	0.71039	0.00001	293	–	–	–
O16c		central burial	male adult	complex catacomb with dromoi	? (destroyed)	Scythian	x	6 individuals (3 adults, 3 children)	2 horse burials with equipment	? (destroyed)		50–55 years	male	mandibula M3	0.70986	0.00001	131	–	–	–

Notes:
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

lab ID	kurgan	grave	individual	tomb type	orientation	relative date	primary burial	burial	burial objects	position of skeleton	absolute date	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_c$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
Ordzhonikidze																				
O15	15	1		complex catacomb with dromoi	? (destroyed)	Scythian	x	double?	x (destroyed)	(destroyed)	4th c. BC	30–40 years	male	maxilla M2	0.71008	0.00001	106	−5.55	–	–
O12	15	2		complex catacomb with dromoi	? (destroyed)	Scythian	x	double?	x (destroyed)	(destroyed)	4th c. BC	40–45 years	female	mandibula? M3	0.71005	0.00001	167	−5.20	–	–
O9	32	4	gracile skeleton	catacomb	W–E	Scythian		double	x (destroyed, platelegs in grave 4)	supine	4th c. BC	50–60 years	female	mandibula M2	0.70993	0.00001	105	−4.34	–	–
O14	32	4	robust skeleton	catacomb	W–E	Scythian		double	x (destroyed, platelegs in grave 4)	supine	4th c. BC	50–60 years	male	maxilla M3?	0.70996	0.00001	61	−5.23	–	–
O11	33	1		catacomb	SW–NE	Scythian		single	x (destroyed)	?	4th c. BC	40–50 years	male	maxilla M2	0.70990	0.00001	144	−4.00	–	–
O13	33	3		catacomb	W–E	Scythian		double (+infant)	x (destroyed)	supine	355–345 BC**	40–50 years	female	maxilla M3	0.70986	0.00001	94	−5.70	–	–
dentine																				
O15c	15	1		complex catacomb with dromoi	? (destroyed)	Scythian	x	double?	x (destroyed)	(destroyed)	4th c. BC	30–40 years	male	maxilla M2	0.70987	0.00001	144	–	–	–
O13c	33	3		catacomb	W–E	Scythian		double (+infant)	x (destroyed)	supine	355–345 BC**	40–50 years	female	maxilla M3	0.70987	0.00001	101	–	–	–

Notes:
* dating of amphorae
** amphora stamp
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Zolotaya Balka																				
lab ID	**kurgan**	**grave**	**individual**	**tomb type**	**orientation**	**relative date**	**primary burial**	**burial**	**burial objects**	**position of skeleton**	**absolute date**	**age at death**	**sex**	**sampled tooth**	**$^{87}Sr/^{86}Sr$**	**2 S.E.**	**Sr concentration (ppm)**	**$\delta^{18}O_c$ (‰ vs. V-PDB)**	**$\delta^{15}N$ (bone, ‰ vs. AIR)**	**$\delta^{13}C$ (bone, ‰ vs. V-PDB)**
O7	13	1		catacomb with dromoi	? (destroyed)	Scythian	x	single	x (destroyed)	? (destroyed)	4th c. BC*			maxilla M1	0.71011	0.00001	99	–5.00	–	–
O2	15	1	'mistress'	catacomb with dromoi	W–E	Scythian	x	double	x (destroyed)	supine	4th c. BC*	22–25 years	female	mandibula M1	0.70981	0.00001	98	–4.66	–	–
O5	15	1	'servant'	catacomb with dromoi	SW–NE	Scythian	x	double	x (destroyed)	supine	4th c. BC*	12–13 years (15–17)		maxilla M1	0.70994	0.00001	261	–6.10	–	–
O8	15	2		catacomb with dromoi	? (destroyed)	Scythian	x	single	x (destroyed)	? (destroyed)	4th c. BC*	45–55 years	male	mandibula M3	0.70917	0.00001	223	–5.98	–	–
O10	15	3	'mistress' (individual 1)	catacomb with dromoi	N–S	Scythian	x	double	x (destroyed)	supine	4th c. BC*	20–22 years	female	maxilla M2	0.70986	0.00001	82	–6.67	–	–
O6	22	1	(individual 1)	catacomb with dromoi	? (destroyed)	Scythian	x	double	x (destroyed)	? (destroyed)	4th c. BC*	old adult ?	female	mandibula M3	0.71002	0.00001	113	–5.65	–	–
dentine																				
O7c	13	1		catacomb with dromoi	? (destroyed)	Scythian	x	single	x (destroyed)	? (destroyed)	4th c. BC*			maxilla M1	0.70970	0.00001	1062	–	–	–
O8c	15	2		catacomb with dromoi	? (destroyed)	Scythian	x	single	x (destroyed)	? (destroyed)	4th c. BC*	45–55 years	male	mandibula M3	0.70939	0.00001	266	–	–	–

Notes:
* dating of amphorae
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Berel' (humans)																					
lab ID	kurgan	individual	no. humans/kurgan	no. horses/kurgan	tomb type	orientation	relative date	primary burial	burial	burial objects	position of skeleton	absolute date	age at death	sex	sampled tooth ***	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_c$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
Be 2	9	?	2	5	wooden chamber	NE–SW	Scythian	x	double	golden earrings, mirror in case, mortar, several bone arrowheads, bronze arrowhead, miniature bronze censer including 8 pebbles and plant seeds, gilded wooden Sphinxfigure, buttons, remains of organic material	supine	4th–3rd c. BC	**	2 (male, young female?)	maxilla l M3	0.71124	0.00001	48	–9.00	–	–
Be 11	10		1	10	wooden chamber	NE–SW	Scythian	x	single	vessel, table top (fragmentary) with 4 table legs, remains of sheep and iron knife (on table), in looter's shaft: quiver (fragmentary) with arrows and 6 bone arrowheads, belt buckle (/sheet metal), belt buckle of bone with deer ornamentation, buttons with carved decoration	supine	4th–3rd c. BC	**	female?*	maxilla M1	0.71115	0.00001	82	–7.73	–	–
Be 5	10		1	10	wooden chamber	NE–SW	Scythian	x	single	vessel, table top (fragmentary) with 4 table legs, remains of sheep and iron knife (on table), in looter's shaft: quiver (fragmentary) with arrows and 6 bone arrowheads, belt buckle (/sheet metal), belt buckle of bone with deer ornamentation, buttons with carved decoration	supine	4th–3rd c. BC	**	female?*	mandibula r PM1	0.71074	0.00001	60	–10.63	–	–
Be 12	16**														maxilla M3	0.71078	0.00001	225	–9.00	–	–
Be 3	32		1	1	wooden chamber	NE–SW	Scythian	x	single	gold foil (fragmentary) as part of clothes, demilune pendant	(not visible)	4th–3rd c. BC	**	male?*	maxilla l M3	0.71153	0.00001	95	–10.07	–	–
Be 13	32		1	1	wooden chamber	NE–SW	Scythian	x	single	gold foil (fragmentary) as part of clothes, demilune pendant	(not visible)	4th–3rd c. BC	**	male?*	maxilla l M3	0.71142	0.00001	98	–10.00	–	–
Be 8	34	?	3	2	wooden chamber(?)	SW–NE	Scythian	? (1 primary, 2 secondary)	? (1 single, 1 double)	2 jars, iron knife, bone buckle, beads of different materials, gold foil	supine (secondary burials?: skulls disembodied)	4th–3rd c. BC	**	3 (2 male?, female?*)	maxilla r incisor	0.71167	0.00001	98	–9.84	–	–
Be 4	72		1	1	wooden chamber	NE–SW	Scythian	x	single	9 bone arrow heads, ceramic vessel, bones of sheep/goat, iron knife(?), iron chisel	crouched on the right	4th–3rd c. BC	**	male?*	maxilla l M3	0.71146	0.00001	99	–9.00	–	–

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Berel' (humans) cont.																					
lab ID	kurgan	individual	no. humans/kurgan	no. horses/kurgan	tomb type	orientation	relative date	primary burial	burial	burial objects	position of skeleton	absolute date	age at death	sex	sampled tooth ***	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_c$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
dentine																					
Be 2c	9	?	2	5	wooden chamber	NE–SW	Scythian	x	double	golden earrings, mirror in case, mortar, several bone arrowheads, bronze arrowhead, miniature bronze censer including 8 pebbles and plant seeds, gilded wooden Sphinxfigure, buttons, remains of organic material	supine	4th–3rd c. BC	**	2 (male, young female?)	maxilla l M3	0.71115	0.00001	61	–	–	–
Be 5c	10		1	10	wooden chamber	NE–SW	Scythian	x	single	vessel, table top (fragmentary) with 4 table legs, remains of sheep and iron knife (on table), in looter's shaft: quiver (fragmentary) with arrows and 6 bone arrowheads, belt buckle (/sheet metal), belt buckle of bone with deer ornamentation, buttons with carved decoration	supine	4th–3rd c. BC	**	female?*	mandibula r PM1	0.71058	0.00001	92	–	–	–
Be 11c	10		1	10	wooden chamber	NE–SW	Scythian	x	single	vessel, table top (fragmentary) with 4 table legs, remains of sheep and iron knife (on table), in looter's shaft: quiver (fragmentary) with arrows and 6 bone arrowheads, belt buckle (/sheet metal), belt buckle of bone with deer ornamentation, buttons with carved decoration	supine	4th–3rd c. BC	**	female?*	maxilla M1	0.71069	0.00001	372	–	–	–
Be 12c	16**														maxilla M3	0.71047	0.00001	347	–	–	–
Be 3c	32		1	1	wooden chamber	NE–SW	Scythian	x	single	gold foil (fragmentary) as part of clothes, demilune pendant	(not visible)	4th–3rd c. BC	**	male?*	maxilla l M3	0.71113	0.00001	115	–	–	–
Be 13c	32		1	1	wooden chamber	NE–SW	Scythian	x	single	gold foil (fragmentary) as part of clothes, demilune pendant	(not visible)	4th–3rd c. BC	**	male?*	maxilla l M3	0.71056	0.00001	255	–	–	–
Be 8c	34	?	2	2	wooden chamber(?)	SW–NE	Scythian	? (1 primary, 2 secondary)	? (1 single, 1 double)	2 jars, iron knife, bone buckle, beads of different materials, gold foil	supine (secondary burials?: skulls disembodied)	4th–3rd c. BC	**	3 (2 male?, female?*)	maxilla r incisor	0.71048	0.00001	303	–	–	–
Be 4c	72		1	1	wooden chamber	NE–SW	Scythian	x	single	9 bone arrow heads, ceramic vessel, bones of sheep/goat, iron knife(?), iron chisel	crouched on the right	4th–3rd c. BC	**	male?*	maxilla l M3	0.71127	0.00001	112	–	–	–

Notes:
* archaeological identification
** no data
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Berel' (horses)																						
lab ID	kurgan	individual	no. humans/kurgan	no. horses/kurgan	tomb type	orientation	relative date	primary burial	burial	burial objects	position of skeleton	absolute date	age at death	sex	sampled tooth ***	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_C$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
Be 6.1	9		2 (male, female?*)	5	wooden chamber		Scythian	x (behind wooden construction)		fragments of bridle, iron snaffle, figural applications (griffin heads), shield fragments		4th–3rd c. BC			vertical	0.71241	0.00001	403	−10.49	–	–
Be 6.2	9		2 (male, female?*)	5	wooden chamber		Scythian	x (behind wooden construction)		fragments of bridle, iron snaffle, figural applications (griffin heads), shield fragments		4th–3rd c. BC			cusp	0.71216	0.00001	–	−10.91	–	–
Be 6.3	9		2 (male, female?*)	5	wooden chamber		Scythian	x (behind wooden construction)		fragments of bridle, iron snaffle, figural applications (griffin heads), shield fragments		4th–3rd c. BC			cervix	0.71221	0.00001	–	−10.52	–	–
Be 7.1	10		1 (female?*)	10	wooden chamber		Scythian	x		bridle,10 saddles with unique applications (ornamentation of fabulous creatures)		4th–3rd c. BC			vertical	0.71129	0.00001	424	−9.73	–	–
Be 7.2	10		1 (female?*)	10	wooden chamber		Scythian	x		bridle, 10 saddles with unique applications (ornamentation of fabulous creatures)		4th–3rd c. BC			cusp	0.71122	0.00001	–	−10.46	–	–
Be 7.3	10		1 (female?*)	10	wooden chamber		Scythian	x		bridle, 10 saddles with unique applications (ornamentation of fabulous creatures)		4th–3rd c. BC			cervix	0.71140	0.00001	–	−9.56	–	–
Be 1.1	11	F'	2 (male?, female?*)	13	wooden chamber		Scythian	x		> 1000 objects (see publication) including bridle etc.		4th–3rd c. BC			vertical	0.71255	0.00001	–	−11.18	–	–
Be 1.2	11	F'	2 (male?, female?*)	13	wooden chamber		Scythian	x		> 1000 objects (see publication) including bridle etc.		4th–3rd c. BC			cusp	0.71264	0.00001	653	**	–	–
Be 1.3	11	F'	2 (male?, female?*)	13	wooden chamber		Scythian	x		> 1000 objects (see publication) including bridle etc.		4th–3rd c. BC			cervix	0.71259	0.00001	–	**	–	–
Be 10.1	18		1 (male?*)	3	wooden chamber		Scythian	x		fragment of iron snaffle, bridle etc.		4th–3rd c. BC			vertical	0.71097	0.00002	482	−9.69	–	–
Be 10.2	18		1 (male?*)	3	wooden chamber		Scythian	x		fragment of iron snaffle, bridle etc.		4th–3rd c. BC			cusp	0.71094	0.00001	–	−12.50	–	–
Be 10.3	18		1 (male?*)	3	wooden chamber		Scythian	x		fragment of iron snaffle, bridle etc.		4th–3rd c. BC			cervix	0.71073	0.00001	–	−10.58	–	–
Be 9.1	23		1 (male?*)	1	stone cist		Scythian	x		bridle etc.		4th–3rd c. BC			vertical	0.71110	0.00001	521	−9.43	–	–
Be 9.2	23		1 (male?*)	1	stone cist		Scythian	x		bridle etc.		4th–3rd c. BC			cusp	0.71121	0.00001	–	−11.85	–	–
Be 9.3	23		1 (male?*)	1	stone cist		Scythian	x		bridle etc.		4th–3rd c. BC			cervix	0.71060	0.00001	–	−11.97	–	–
dentine																						
Be 6c	9		2 (male, female?*)	5	wooden chamber		Scythian	x (behind wooden construction)		fragments of bridle, iron snaffle, figural applications (griffin heads), shield fragments		4th–3rd c. BC				0.71217	0.00001	681	–	–	–
Be 7c	10		1 (female?*)	10	wooden chamber		Scythian	x		bridle etc., 10 saddles with unique applications (ornamentation of fabulous creatures)		4th–3rd c. BC				0.71136	0.00001	632	–	–	–
Be 1c	11		2 (male?, female?*)	13	wooden chamber		Scythian	x		> 1000 objects (see publication), bridle etc.		4th–3rd c. BC				0.71213	0.00001	709	–	–	–
Be 10c	18		1 (male?*)	3	wooden chamber		Scythian	x		fragment of iron snaffle, bridle etc.		4th–3rd c. BC				0.71060	0.00001	948	–	–	–
Be 9c	23		1 (male?*)	1	stone cist		Scythian	x		bridle etc.		4th–3rd c. BC				0.71064	0.00001	611	–	–	–

Notes:
* archaeological identification
** no data
*** no tooth identification
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Zauschwitz																			
lab ID	grave	individual	tomb type	grave shape	orientation	relative date	burial	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_c$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
Z 1	human burial	east	flat grave	almost rectangular (4.2m × 1.8m)	E–W	Globular Amphora Culture	double	stone tool, bone tool, ceramic vessel, boar tooth, 2 animal bones; boar tooth between both skeletons	crouched on the left		old adult	male	mandibula M1	0.71310	0.00001	99	–4.83	–	–
Z 2	human burial	east	flat grave	almost rectangular (4.2m × 1.8m)	E–W	Globular Amphora Culture	double	stone tool, bone tool, ceramic vessel, boar tooth, 2 animal bones; boar tooth between both skeletons	crouched on the left		old adult	male	mandibula M2	0.71380	0.00001	81	–4.51	–	–
Z 3	human burial	west	flat grave	almost rectangular (4.2m × 1.8m)	W–E	Globular Amphora Culture	double	stone tool, 4 ceramic vessels; boar tooth between both skeletons	crouched on the right		juvenile	male ?	maxilla M1	0.71235	0.00001	111	–4.37	–	–
Z 4	human burial	west	flat grave	almost rectangular (4.2m × 1.8m)	W–E	Globular Amphora Culture	double	stone tool, 4 ceramic vessels; boar tooth between both skeletons	crouched on the right		juvenile	male ?	maxilla M2	0.71272	0.00001	122	–4.76	–	–
dentine																			
Z 2c	human burial	east	flat grave	almost rectangular (4.2m × 1.8m)	E–W	Globular Amphora Culture	double	stone tool, bone tool, ceramic vessel, boar tooth, 2 animal bones; boar tooth between both skeletons	crouched on the left		old adult	male	mandibula M2	0.71191	0.00001	175	–	–	–
Z 3c	human burial	west	flat grave	almost rectangular (4.2m × 1.8m)	W–E	Globular Amphora Culture	double	stone tool, 4 ceramic vessels; boar tooth between both skeletons	crouched on the right		juvenile	male	maxilla M1	0.71150	0.00001	–	–	–	–
Z 4c	human burial	west	flat grave	almost rectangular (4.2m × 1.8m)	W–E	Globular Amphora Culture	double	stone tool, 4 ceramic vessels; boar tooth between both skeletons	crouched on the right		juvenile	male	maxilla M2	0.71160	0.00001	218	–	–	–
cattle																			
Z 5.1	cattle burial	cattle I	pit	pear-shaped (4.75m × 1.5–2.7m)	W–E	Globular Amphora Culture	3 cattle	7 ceramic vessels (in pit with 3 cattle)	on right side		7–9 years	female	M2 cusp	0.71307	0.00001	326	–5.03	–	–
Z 5.2	cattle burial	cattle I	pit	pear-shaped (4.75m × 1.5–2.7m)	W–E	Globular Amphora Culture	3 cattle	7 ceramic vessels (in pit with 3 cattle)	on right side		7–9 years	female	M2 centre	0.71316	0.00001	–	–7.05	–	–
Z 5.3	cattle burial	cattle I	pit	pear-shaped (4.75m × 1.5–2.7m)	W–E	Globular Amphora Culture	3 cattle	7 ceramic vessels (in pit with 3 cattle)	on right side		5–7 years	female	M2 cervix	0.71411	0.00001	–	–7.82	–	–
Z 6.1	cattle burial	cattle II	pit	pear-shaped (4.75m × 1.5–2.7m)	E–W	Globular Amphora Culture	3 cattle	7 ceramic vessels (in pit with 3 cattle)	sitting		5–7 years	male	maxilla M1 cusp	0.71250	0.00001	273	–7.21	–	–
Z 6.2	cattle burial	cattle II	pit	pear-shaped (4.75m × 1.5–2.7m)	E–W	Globular Amphora Culture	3 cattle	7 ceramic vessels (in pit with 3 cattle)	sitting		5–7 years	male	maxilla M1 centre	0.71341	0.00001	–	–8.43	–	–
Z 6.3	cattle burial	cattle II	pit	pear-shaped (4.75m × 1.5–2.7m)	E–W	Globular Amphora Culture	3 cattle	7 ceramic vessels (in pit with 3 cattle)	sitting		5–7 years	male	maxilla M1 cervix	0.71386	0.00001	–	–7.03	–	–

Appendix A II Table 1 cont. | Archaeological and anthropological context information and isotope data. Sites are arranged alphabetically according to regions.

Zauschwitz cont.																			
lab ID	grave	individual	tomb type	grave shape	orientation	relative date	burial	burial objects	position of skeleton	absolute date (BP)	age at death	sex	sampled tooth	$^{87}Sr/^{86}Sr$	2 S.E.	Sr concentration (ppm)	$\delta^{18}O_C$ (‰ vs. V-PDB)	$\delta^{15}N$ (bone, ‰ vs. AIR)	$\delta^{13}C$ (bone, ‰ vs. V-PDB)
Z 7.1	cattle burial	cattle III	pit	pear-shaped (4.75m × 1.5–2.7m)	E–W	Globular Amphora Culture	3 cattle	7 ceramic vessels (in pit with 3 cattle)	sitting		5–7 years	male	M1 cusp	0.71246	0.00001	227	–6.5	–	–
Z 7.2	cattle burial	cattle III	pit	pear-shaped (4.75m × 1.5–2.7m)	E–W	Globular Amphora Culture	3 cattle	7 ceramic vessels (in pit with 3 cattle)	sitting		5–7 years	male	M1 centre	0.71267	0.00001	–	–6.42	–	–
Z 7.3	cattle burial	cattle III	pit	pear-shaped (4.75m × 1.5–2.7m)	E–W	Globular Amphora Culture	3 cattle	7 ceramic vessels (in pit with 3 cattle)	sitting		5–7 years	male	M1 cervix	0.71294	0.00003	–	–6.07	–	–

Notes:
Information on $\delta^{18}O$ standard errors for individual samples was not provided by the RLAHA, University of Oxford. Information on $\delta^{13}C$ and $\delta^{15}N$ standard errors is provided in Appendix D.

Appendix B

Appendix B Table 1 | Gender-related mean and median $^{87}Sr/^{86}Sr$ values including standard deviations.

site	sex	n individuals	n samples	$^{87}Sr/^{86}Sr$ median	$^{87}Sr/^{86}Sr$ mean	± 1σ
Eneolithic and Bronze Age						
Bulgaria						
Benkovski	male	6	8	0.70812	0.70840	0.00051
	?	3	3	0.70811	0.70811	0.00003
Boyanovo	undetermined	5	7	0.70879	0.70867	0.00070
Ovchartsi	male	4	7	0.70911	0.70924	0.00061
	?	1	1		0.70977	
Smyadovo	male	4	5	0.70890	0.70877	0.00035
	female	2	2		0.70836	0.00024
	?	2	3	0.70672	0.70710	0.00096
Hungary						
Hungary (all sites)	male	12	14	0.71010	0.71024	0.00081
	female	3	4	0.71000	0.71001	0.00012
	?	5	7	0.71016	0.71001	0.00043
Ukraine						
Kirovograd	male	6	10	0.71055	0.71046	0.00057
	?	2	4	0.71097	0.71119	0.00059
Nevskoe	male	1	1		0.70912	
	?	4	4	0.70916	0.70915	0.00009
Peshtchanka	male	4	8	0.71027	0.70984	0.00042
	female	1	2		0.71049	0.00002
	?	1	2		0.71041	0.00005
	undetermined	1	2		0.70984	0.00008
Shakhta Stepnaya	male	1	2		0.70996	0.00003
	female	2	3	0.70999	0.71027	0.00013
	?	1	2		0.70996	0.00001
Vinogradnoe	male	12	18	0.70984	0.70986	0.00014
	female	3	4	0.70971	0.70969	0.00019
	?	1	2		0.70961	0.00000
Russia						
Kalinovka I	male	2	2		0.70877	0.00022
	female	1	1		0.70869	
Nikolaevka III	male	6	7	0.70887	0.70888	0.00028
	female	1	1		0.70874	
	?	1	1		0.70888	
Olennii	male	1	1		0.70949	
	female	1	1		0.70951	
	?	5	5	0.70950	0.70956	0.00015

Appendix B Table 1 cont. | Gender-related mean and median $^{87}Sr/^{86}Sr$ values including standard deviations.

site	sex	n individuals	n samples	$^{87}Sr/^{86}Sr$ median	$^{87}Sr/^{86}Sr$ mean	± 1σ
Podlesnyi	male	2	3	0.70863	0.70888	0.00075
	female	1	1		0.70880	
Politotdel'skoe	male	1	1		0.70916	
	?	2	2		0.70892	0.00015
Sukhaya Termista II	male	2	4	0.70906	0.70904	0.00011
	female	1	2		0.70917	0.00001
	?	1	2		0.70903	0.00016
Iron Age (Scythian period)						
Ukraine	male	11	11	0.70992	0.70985	0.00026
	female	7	7	0.70994	0.71004	0.00032
	?	3	3	0.70994	0.70986	0.00034
Berel' (Kazakhstan)	undetermined (only archaeologically)	6	8	0.71133	0.71125	0.00034

Appendix B Table 2 | Age-related mean and median $^{87}Sr/^{86}Sr$ values including standard deviations.

site	age	n individuals	n samples	median $^{87}Sr/^{86}Sr$	mean $^{87}Sr/^{86}Sr$	± 1σ
Eneolithic and Bronze Age						
Bulgaria						
Benkovski	infant	1	1		0.70811	
	juvenile	2	3	0.70916	0.70885	0.00063
	adult	1	1		0.70812	
	mature	3	4	0.70809	0.70813	0.00011
	?	2	2		0.70812	0.00004
Boyanovo	undetermined	5	7	0.70879	0.70867	0.00070
Ovchartsi	juvenile	1	1		0.70976	
	adult	2	4	0.70884	0.70880	0.00034
	mature	1	2		0.70984	0.00032
	?	1	1		0.70977	
Smyadovo	infant	1	1		0.70819	
	juvenile	1	2		0.70656	0.00023
	adult	6	7	0.70878	0.70865	0.00036
Hungary						
Hungary (all sites)	infant	2	3	0.71016	0.71016	0.00005
	juvenile	3	4	0.70979	0.70974	0.00040
	adult	11	13	0.71004	0.71005	0.00068
	mature	4	5	0.71090	0.71061	0.00058

Appendix B Table 2 cont. | Age-related mean and median $^{87}Sr/^{86}Sr$ values including standard deviations.

site	age	n individuals	n samples	median $^{87}Sr/^{86}Sr$	mean $^{87}Sr/^{86}Sr$	± 1σ
Ukraine						
Kirovograd	infant	1	2		0.71158	0.00067
	juvenile	1	2		0.71080	0.00005
	adult	3	5	0.71080	0.71068	0.00059
	mature	3	5	0.71048	0.71025	0.00050
Nevskoe	juvenile	1	1		0.70912	
	adult	4	4	0.70916	0.70905	0.00009
Peshtchanka	juvenile	1	2		0.71041	0.00002
	adult	4	8	0.71030	0.71022	0.00038
	mature	1	2		0.71059	0.00032
	undetermined	1	2		0.71016	0.00008
Shakhta Stepnaya	adult	3	5	0.70998	0.70995	0.00010
	mature	1	2		0.70996	0.00001
Vinogradnoe	juvenile	1	2		0.70961	0.00001
	adult	11	16	0.70982	0.70980	0.00017
	mature	4	7	0.70986	0.70991	0.00011
Russia						
Kalinovka I	mature	2	2		0.70877	0.00022
	senile	1	1		0.70869	
Nikolaevka III	infant	1	1		0.70842	
	juvenile	1	1		0.70888	
	adult	1	1		0.70895	
	mature	5	6	0.70884	0.70892	0.00023
Olennii	infant	4	4	0.70951	0.70958	0.00016
	adult	3	3	0.70949	0.70949	0.00002
Podlesnyi	juvenile	1	1		0.70972	
	adult	1	2		0.70845	0.00025
	mature	1	1		0.70972	
Politotdel'skoe	infant	1	1		0.70902	
	adult	1	1		0.70881	
	mature	1	1		0.70916	
Sukhaya Termista II	adult	2	4	0.70914	0.70912	0.00008
	mature	1	2		0.70903	0.00018
	?	1	2		0.70903	0.00016
Iron Age (Scythian period)						
Ukraine	juvenile	3	3	0.70994	0.71006	0.00062
	adult	7	7	0.70992	0.70994	0.00012
	mature	10	10	0.70992	0.70983	0.00026
	?	1	1	0.70994	0.70986	0.00034
Berel' (Kazakhstan)	undetermined	6	8	0.71133	0.71125	0.00034

Appendix B Table 3 | Chronological groups: Mean and median $^{87}Sr/^{86}Sr$ values including standard deviations.

site	cultural period	n individuals	n samples	$^{87}Sr/^{86}Sr$ median	$^{87}Sr/^{86}Sr$ mean	± 1σ
Eneolithic and Bronze Age						
Bulgaria						
Benkovski	Early Bronze Age/ Yamnaya	9	11	0.70812	0.70832	0.00044
Boyanovo	Early Bronze Age/ Yamnaya	4	5	0.70879	0.70874	0.00062
	Middle Bronze Age	1	2		0.70851	0.00113
Ovchartsi	Early Bronze Age/ Yamnaya	5	8	0.70936	0.70930	0.00057
Smyadovo	Eneolithic/Copper Age	7	9	0.70819	0.70797	0.00107
	Early Bronze Age/ Yamnaya	1	1		0.70836	
Hungary						
Hungary (all sites)	Eneolithic/Copper Age	1	2		0.71005	0.00013
	Early Bronze Age/ Yamnaya	19	23	0.71010	0.71014	0.00065
Ukraine						
Kirovograd	Early Bronze Age/Yamnaya	7	12	0.71078	0.71067	0.00070
	Middle Bronze Age/ Catacomb culture	1	2		0.71065	0.00005
Nevskoe	Middle Bronze Age/ Catacomb culture	5	5	0.70912	0.70915	0.00008
Peshtchanka	Eneolithic/Copper Age	4	8	0.71041	0.71027	0.00044
	Early Bronze Age/ Yamnaya	2	4	0.71029	0.71029	0.00014
	Middle Bronze Age/ Catacomb culture	1	2		0.71016	0.00008
Shakhta Stepnaya	Early Bronze Age/ Yamnaya	2	4	0.70996	0.70996	0.00002
	Middle Bronze Age/ Catacomb culture	2	3	0.70999	0.70993	0.00013
Vinogradnoe	Eneolithic/Copper Age	2	2		0.71002	0.00016
	Early Bronze Age/ Yamnaya	4	7	0.70983	0.70979	0.00013
	Middle Bronze Age/ Catacomb culture	10	16	0.70982	0.70980	0.00017
Russia						
Olennii	Novotitarovskaya	7	7	0.70950	0.70954	0.00013
Sukhaya Termista II	Middle Bronze Age/ Catacomb culture	4	8	0.70912	0.70907	0.00011
Volga (all sites)	Poltavka	17	19	0.70881	0.70886	0.00032
Iron Age (Scythian period)						
Ukraine	Scythian	21	21	0.70994	0.70991	0.00029
Berel' (Kazakhstan)	Scythian	6	8	0.71133	0.71125	0.00034

Appendix C

Appendix C Table 1 | Results of $\delta^{18}O$ analysis for all human individuals, sorted by sample sites and a range of equations for the conversion of $\delta^{18}O_{carbonate}$ and $\delta^{18}O_{phosphate}$ to $\delta^{18}O_{water}$. Sites are arranged alphabetically according to regions. All values are given in ‰. Equations 1 to 6 are expressed vs. V-SMOW.

ID	$\delta^{18}O_{carbonate}$ (vs. V-PDB)	$\delta^{18}O_{carbonate}$ (vs. V-SMOW)	$\delta^{18}O_{phosphate}$ (vs. V-SMOW)	$\delta^{18}O_w$ (1) (Longinelli)	$\delta^{18}O_w$ (2) (Luz)	$\delta^{18}O_w$ (3) (Levinson)	$\delta^{18}O_w$ (4) (Daux)	$\delta^{18}O_w$ (5) (Pollard)	$\delta^{18}O_w$ (6) (Chenery)
Eneolithic and Bronze Age									
Bulgaria									
Benkovski									
Ben 1	–3.29	27.51	18.46	–6.05	–5.26	–2.87	–5.29	–4.88	–4.89
Ben 2	–3.38	27.42	18.37	–6.19	–5.37	–3.05	–5.43	–5.02	–5.04
Ben 3	–4.04	26.74	17.71	–7.20	–6.17	–4.33	–6.45	–6.04	–6.12
Ben 4	–4.08	26.71	17.67	–7.26	–6.21	–4.40	–6.50	–6.10	–6.17
Ben 5	–4.94	25.82	16.80	–8.59	–7.26	–6.08	–7.85	–7.45	–7.58
Ben 6	–5.18	25.57	16.56	–8.97	–7.55	–6.56	–8.22	–7.82	–7.98
Ben 7	–4.03	26.76	17.72	–7.18	–6.15	–4.31	–6.43	–6.02	–6.09
Ben 8	–3.57	27.23	18.18	–6.48	–5.60	–3.42	–5.72	–5.31	–5.34
Ben 9	–4.74	26.03	17.01	–8.28	–7.01	–5.68	–7.53	–7.12	–7.25
Ben 10	–4.20	26.58	17.55	–7.45	–6.36	–4.64	–6.69	–6.29	–6.37
Ben 11	–4.34	26.44	17.41	–7.66	–6.53	–4.91	–6.91	–6.50	–6.59
Boyanovo									
Bo 1	–5.60	25.13	16.13	–9.62	–8.06	–7.38	–8.88	–8.49	–8.68
Bo 2	–4.27	26.51	17.48	–7.55	–6.44	–4.77	–6.80	–6.40	–6.48
Bo 3	–3.75	27.05	18.01	–6.75	–5.81	–3.76	–5.99	–5.57	–5.62
Bo 4	–4.92	25.84	16.83	–8.56	–7.23	–6.04	–7.81	–7.40	–7.55
Bo 5	–3.42	27.38	18.33	–6.25	–5.42	–3.13	–5.49	–5.08	–5.10
Bo 11	–4.86	25.90	16.89	–8.46	–7.16	–5.92	–7.72	–7.31	–7.45
Bo 12	–4.41	26.36	17.33	–7.78	–6.62	–5.06	–7.03	–6.63	–6.72
Ovchartsi									
OV 1	–4.49	26.28	17.25	–7.91	–6.72	–5.21	–7.15	–6.75	–6.85
OV 2	–4.60	26.17	17.15	–8.06	–6.84	–5.42	–7.31	–6.91	–7.02
OV 3	–4.00	26.79	17.75	–7.14	–6.12	–4.25	–6.38	–5.98	–6.04
OV 4	–5.18	25.57	16.55	–8.97	–7.55	–6.56	–8.23	–7.84	–7.98
OV 5	–3.52	27.28	18.23	–6.40	–5.54	–3.32	–5.64	–5.23	–5.26
OV 6	–3.60	27.20	18.15	–6.52	–5.63	–3.47	–5.76	–5.36	–5.39
OV 11	–4.56	26.21	17.18	–8.01	–6.80	–5.35	–7.26	–6.86	–6.96
OV 12	–3.92	26.87	17.83	–7.02	–6.03	–4.10	–6.26	–5.85	–5.91
Smyadovo									
SM 1	–3.84	26.96	17.92	–6.89	–5.92	–3.93	–6.13	–5.71	–5.77
SM 3	–5.42	25.33	16.32	–9.33	–7.84	–7.01	–8.59	–8.19	–8.36
SM 4	–5.83	24.90	15.90	–9.97	–8.34	–7.82	–9.23	–8.85	–9.04
SM 5	–6.68	24.03	15.04	–11.28	–9.37	–9.47	–10.55	–10.18	–10.43
SM 6	–5.62	25.12	16.12	–9.64	–8.08	–7.41	–8.90	–8.50	–8.69
SM 7	–6.11	24.61	15.62	–10.41	–8.68	–8.37	–9.67	–9.28	–9.50
SM 8	–6.71	23.99	15.01	–11.33	–9.40	–9.53	–10.60	–10.22	–10.49
SM 11	–5.56	25.18	16.18	–9.55	–8.00	–7.28	–8.80	–8.41	–8.60
SM 12	–6.41	24.30	15.31	–10.87	–9.05	–8.96	–10.14	–9.76	–10.00
Hungary									
Sárrétudvari-Őrhalom									
HU 1	–6.98	23.72	14.74	–11.75	–9.73	–10.06	–11.02	–10.64	–10.92
HU 2	–6.78	23.92	14.94	–11.44	–9.49	–9.67	–10.71	–10.33	–10.60
HU 3	–4.10	26.68	17.65	–7.30	–6.24	–4.45	–6.54	–6.13	–6.21
HU 4	–4.73	26.04	17.01	–8.27	–7.00	–5.67	–7.52	–7.12	–7.23
HU 5	–6.46	24.25	15.27	–10.94	–9.10	–9.05	–10.21	–9.82	–10.08

Appendix C Table 1 cont. | Results of $\delta^{18}O$ analysis for all human individuals, sorted by sample sites and a range of equations for the conversion of $\delta^{18}O_{carbonate}$ and $\delta^{18}O_{phosphate}$ to $\delta^{18}O_{water}$. Sites are arranged alphabetically according to regions. All values are given in ‰. Equations 1 to 6 are expressed vs. V-SMOW.

ID	$\delta^{18}O_{carbonate}$ (vs. V-PDB)	$\delta^{18}O_{carbonate}$ (vs. V-SMOW)	$\delta^{18}O_{phosphate}$ (vs. V-SMOW)	$\delta^{18}O_w$ (1) (Longinelli)	$\delta^{18}O_w$ (2) (Luz)	$\delta^{18}O_w$ (3) (Levinson)	$\delta^{18}O_w$ (4) (Daux)	$\delta^{18}O_w$ (5) (Pollard)	$\delta^{18}O_w$ (6) (Chenery)
Hungary (cont.)									
Sárrétudvari-Őrhalom (cont.)									
HU 6	–4.02	26.76	17.73	–7.18	–6.15	–4.30	–6.42	–6.01	–6.09
HU 7	–6.20	24.52	15.53	–10.54	–8.78	–8.54	–9.81	–9.42	–9.65
HU 8	–4.87	25.89	16.88	–8.48	–7.17	–5.94	–7.73	–7.33	–7.47
HU 24	–4.10	26.68	17.65	–7.30	–6.24	–4.45	–6.54	–6.13	–6.21
HU 25	–6.24	24.48	15.49	–10.60	–8.84	–8.62	–9.87	–9.48	–9.71
HU 26	–4.67	26.10	17.07	–8.18	–6.93	–5.56	–7.42	–7.03	–7.14
HU 27	–4.38	26.39	17.37	–7.73	–6.58	–4.99	–6.98	–6.57	–6.67
Kétegyháza-Kétegyházi tanyák									
HU 15	–4.63	26.14	17.11	–8.12	–6.88	–5.48	–7.36	–6.97	–7.07
HU 16	–5.33	25.42	16.41	–9.19	–7.73	–6.84	–8.45	–8.05	–8.22
HU 17	–4.54	26.23	17.20	–7.98	–6.78	–5.31	–7.23	–6.83	–6.93
HU 18	–5.82	24.91	15.91	–9.95	–8.32	–7.79	–9.21	–8.83	–9.03
Debrecen-Dunahalom									
HU 11	–4.87	25.89	16.87	–8.48	–7.17	–5.95	–7.74	–7.34	–7.47
Ukraine									
Kirovograd									
SU 10	–7.17	23.52	14.55	–12.04	–10.11	–10.43	–11.32	–10.94	–11.24
SU 11	–4.66	26.11	17.08	–8.16	–7.09	–5.54	–7.41	–7.02	–7.13
UK 8	–4.85	25.91	16.89	–8.46	–7.15	–5.91	–7.71	–7.31	–7.44
UK 41	–5.82	24.91	15.91	–9.96	–8.33	–7.81	–9.22	–8.83	–9.03
UK 43	–5.82	24.91	15.91	–9.96	–8.33	–7.80	–9.22	–8.83	–9.03
UK 44	–5.21	25.54	16.53	–9.01	–7.59	–6.61	–8.27	–7.87	–8.03
UK 46	–5.42	25.32	16.31	–9.34	–7.85	–7.03	–8.60	–8.21	–8.38
UK 47	–5.61	25.12	16.12	–9.63	–8.07	–7.40	–8.89	–8.50	–8.69
UK 48	–4.72	26.04	17.02	–8.26	–7.00	–5.66	–7.51	–7.11	–7.23
UK 49	–4.71	26.06	17.04	–8.23	–6.98	–5.63	–7.48	–7.08	–7.20
Nevskoe									
OU 1	–5.81	24.92	15.92	–9.95	–8.32	–7.79	–9.21	–8.81	–9.01
OU 2	–6.00	24.72	15.73	–10.24	–8.55	–8.16	–9.50	–9.11	–9.33
OU 3	–5.54	25.19	16.19	–9.53	–7.99	–7.26	–8.79	–8.40	–8.58
OU 4	–3.95	26.84	17.80	–7.06	–6.06	–4.15	–6.30	–5.90	–5.96
OU 5	–6.13	24.59	15.60	–10.43	–8.70	–8.40	–9.70	–9.31	–9.54
Peshtchanka									
UK 1	–4.99	25.76	16.75	–8.68	–7.32	–6.19	–7.93	–7.53	–7.68
UK 4	–7.79	22.88	13.92	–13.00	–10.71	–11.64	–12.28	–11.91	–12.25
UK 10	–4.77	25.99	16.97	–8.33	–7.05	–5.75	–7.58	–7.19	–7.31
UK 33	–5.71	25.02	16.02	–9.79	–8.20	–7.59	–9.05	–8.66	–8.85
UK 34	–4.92	25.84	16.82	–8.56	–7.24	–6.05	–7.82	–7.42	–7.55
UK 35	–5.43	25.31	16.31	–9.35	–7.85	–7.03	–8.60	–8.21	–8.39
UK 36	–7.53	23.15	14.19	–12.59	–10.39	–11.13	–11.87	–11.50	–11.83
UK 37	–5.81	24.92	15.92	–9.95	–8.32	–7.79	–9.21	–8.81	–9.01
UK 40	–4.66	26.10	17.08	–8.17	–6.92	–5.55	–7.42	–7.02	–7.14
UK 57	–5.79	24.94	15.94	–9.91	–8.29	–7.75	–9.17	–8.78	–8.98
UK 58	–4.18	26.61	17.57	–7.41	–6.33	–4.59	–6.66	–6.26	–6.32
Shakhta Stepnaya									
UK 50	–4.63	26.14	17.12	–8.11	–6.88	–5.48	–7.36	–6.95	–7.07

Appendix C Table 1 cont. | Results of $\delta^{18}O$ analysis for all human individuals, sorted by sample sites and a range of equations for the conversion of $\delta^{18}O_{carbonate}$ and $\delta^{18}O_{phosphate}$ to $\delta^{18}O_{water}$. Sites are arranged alphabetically according to regions. All values are given in ‰. Equations 1 to 6 are expressed vs. V-SMOW.

ID	$\delta^{18}O_{carbonate}$ (vs. V-PDB)	$\delta^{18}O_{carbonate}$ (vs. V-SMOW)	$\delta^{18}O_{phosphate}$ (vs. V-SMOW)	$\delta^{18}O_w$ (1) (Longinelli)	$\delta^{18}O_w$ (2) (Luz)	$\delta^{18}O_w$ (3) (Levinson)	$\delta^{18}O_w$ (4) (Daux)	$\delta^{18}O_w$ (5) (Pollard)	$\delta^{18}O_w$ (6) (Chenery)
Ukraine (cont.)									
Shakhta Stepnaya (cont.)									
UK 51	–5.78	24.95	15.95	–9.90	–8.28	–7.73	–9.16	–9.58	–8.96
UK 53	–5.38	25.37	16.36	–9.27	–7.79	–6.93	–8.52	–8.94	–8.30
UK 54	–4.85	25.91	16.89	–8.46	–7.16	–5.92	–7.71	–8.12	–7.44
UK 55	–4.96	25.80	16.78	–8.62	–7.28	–6.12	–7.87	–8.29	–7.61
UK 56	–5.24	25.51	16.50	–9.06	–7.62	–6.67	–8.31	–8.73	–8.07
Vinogradnoe									
UK 5	–4.49	26.28	17.25	–7.91	–6.72	–5.22	–7.15	–7.56	–6.85
UK 6	–3.62	27.18	18.14	–6.55	–5.66	–3.51	–5.79	–6.18	–5.42
UK 11	–4.19	26.59	17.56	–7.43	–6.35	–4.62	–6.68	–7.08	–6.36
UK 12	–4.67	26.09	17.07	–8.18	–6.94	–5.57	–7.43	–7.84	–7.15
UK 13	–5.13	25.63	16.61	–8.88	–7.48	–6.45	–8.14	–8.55	–7.88
UK 14	–4.27	26.51	17.48	–7.56	–6.45	–4.78	–6.81	–7.21	–6.48
UK 16	–5.08	25.67	16.66	–8.81	–7.43	–6.36	–8.06	–8.48	–7.82
UK 18	–5.96	24.77	15.77	–10.17	–8.50	–8.07	–9.43	–9.86	–9.25
UK 19	–5.90	24.83	15.83	–10.08	–8.42	–7.95	–9.34	–9.76	–9.15
UK 20	–4.69	26.07	17.05	–8.21	–6.96	–5.60	–7.46	–7.87	–7.18
UK 21	–5.45	25.29	16.28	–9.39	–7.88	–7.08	–8.64	–9.07	–8.42
UK 22	–5.01	25.75	16.73	–8.70	–7.34	–6.21	–7.95	–8.37	–7.69
UK 23	–5.11	25.65	16.63	–8.85	–7.46	–6.41	–8.11	–8.52	–7.85
UK 24	–5.99	24.73	15.74	–10.22	–8.53	–8.13	–9.48	–9.90	–9.31
UK 25	–6.17	24.55	15.55	–10.50	–8.75	–8.49	–9.77	–10.20	–9.60
UK 27	–4.89	25.87	16.85	–8.52	–7.20	–5.98	–7.77	–8.18	–7.50
UK 28	–6.59	24.12	15.13	–11.15	–9.26	–9.30	–10.41	–10.85	–10.28
UK 29	–4.90	25.86	16.84	–8.53	–7.21	–6.00	–7.78	–8.20	–7.52
UK 30	–5.51	25.23	16.22	–9.48	–7.95	–7.20	–8.74	–9.16	–8.52
UK 31	–6.35	24.37	15.38	–10.77	–8.96	–8.82	–10.03	–10.46	–9.89
UK 32	–4.42	26.36	17.33	–7.79	–6.63	–5.07	–7.03	–7.44	–6.72
Russia									
Kalinovka I									
WO 4	–5.86	24.87	15.87	–10.02	–8.38	–7.88	–9.28	–9.70	–9.09
WO 5	–7.40	23.28	14.31	–12.40	–10.24	–10.89	–11.68	–12.12	–11.62
WO 6	–6.86	23.84	14.87	–11.56	–9.58	–9.82	–10.83	–11.25	–10.73
Nikolaevka III									
WO 7	–6.17	24.55	15.56	–10.49	–8.75	–8.48	–9.76	–10.18	–9.60
WO 8	–5.77	24.96	15.96	–9.88	–8.27	–7.70	–9.14	–9.56	–8.95
WO 9	–6.79	23.91	14.94	–11.45	–9.50	–9.68	–10.72	–11.14	–10.62
WO 10	–6.66	24.04	15.06	–11.25	–9.34	–9.44	–10.52	–10.96	–10.41
WO 11	–6.87	23.83	14.85	–11.57	–9.60	–9.84	–10.85	–11.28	–10.74
WO 12	–7.01	23.68	14.70	–11.80	–9.77	–10.13	–11.07	–11.52	–10.98
WO 13	–6.35	24.36	15.38	–10.77	–8.97	–8.83	–10.04	–10.46	–9.90
WO 17	–6.33	24.38	15.39	–10.75	–8.95	–8.80	–10.01	–10.45	–9.87
WO 18	–7.21	23.47	14.50	–12.12	–10.02	–10.53	–11.39	–11.83	–11.32
Olennii									
OL 1	–5.64	25.10	16.09	–9.68	–8.11	–7.45	–8.93	–9.36	–8.72
OL 2	–5.33	25.42	16.41	–9.19	–7.73	–6.84	–8.45	–8.86	–8.22
OL 3	–5.40	25.34	16.33	–9.31	–7.82	–6.99	–8.57	–8.99	–8.34

Appendix C Table 1 cont. | Results of $\delta^{18}O$ analysis for all human individuals, sorted by sample sites and a range of equations for the conversion of $\delta^{18}O_{carbonate}$ and $\delta^{18}O_{phosphate}$ to $\delta^{18}O_{water}$. Sites are arranged alphabetically according to regions. All values are given in ‰. Equations 1 to 6 are expressed vs. V-SMOW.

ID	$\delta^{18}O_{carbonate}$ (vs. V-PDB)	$\delta^{18}O_{carbonate}$ (vs. V-SMOW)	$\delta^{18}O_{phosphate}$ (vs. V-SMOW)	$\delta^{18}O_w$ (1) (Longinelli)	$\delta^{18}O_w$ (2) (Luz)	$\delta^{18}O_w$ (3) (Levinson)	$\delta^{18}O_w$ (4) (Daux)	$\delta^{18}O_w$ (5) (Pollard)	$\delta^{18}O_w$ (6) (Chenery)
Russia (cont.)									
Olennii (cont.)									
OL 4	–4.87	25.89	16.87	–8.49	–7.18	–5.95	–7.74	–7.34	–7.47
OL 5	–4.93	25.83	16.81	–8.58	–7.25	–6.06	–7.83	–7.43	–7.56
OL 6	–4.89	25.87	16.85	–8.52	–7.20	–5.99	–7.77	–7.37	–7.50
OL 7	–4.66	26.10	17.08	–8.17	–6.92	–5.55	–7.42	–7.02	–7.14
Podlesnyi									
WO 14	–6.30	24.41	15.42	–10.70	–8.91	–8.74	–9.97	–9.59	–9.82
WO 15	–5.29	25.45	16.44	–9.14	–7.69	–6.77	–8.40	–8.01	–8.17
WO 16	–6.53	24.18	15.20	–11.05	–9.18	–9.18	–10.32	–9.93	–10.19
WO 19	–8.11	22.55	13.60	–13.49	–11.10	–12.26	–12.77	–12.41	–12.78
Politotdel'skoe									
WO 1	–5.58	25.16	16.16	–9.58	–8.03	–7.32	–8.83	–8.44	–8.63
WO 2	–4.80	25.96	16.94	–8.38	–7.09	–5.81	–7.63	–7.23	–7.36
WO 3	–6.07	24.65	15.66	–10.34	–8.63	–8.28	–9.60	–9.22	–9.44
Sukhaya Termista II									
RE 1	–5.54	25.20	16.20	–9.52	–7.98	–7.25	–8.77	–8.38	–8.57
RE 2	–6.47	24.24	15.25	–10.96	–9.11	–9.07	–10.23	–9.85	–10.09
RE 3	–5.72	25.02	16.02	–7.91	–6.72	–5.22	–7.15	–8.66	–8.85
RE 4	–5.55	25.18	16.18	–9.54	–8.00	–7.28	–8.80	–8.41	–8.60
RE 5	–5.65	25.09	16.09	–9.69	–8.12	–7.46	–8.95	–8.55	–8.74
RE 6	–4.52	26.25	17.23	–7.94	–6.75	–5.26	–7.19	–6.78	–6.90
RE 7	–5.11	25.65	16.63	–8.85	–7.46	–6.41	–8.11	–7.71	–7.85
RE 8	–5.33	25.41	16.40	–9.20	–7.74	–6.85	–8.46	–8.07	–8.23
Iron Age (Scythian period)									
Ukraine									
Alexandropol'									
AL 1	–6.07	24.65	15.66	–10.34	–8.78	–8.29	–9.60	–9.22	–9.44
AL 2	–4.58	26.19	17.16	–8.04	–7.00	–5.39	–7.29	–6.89	–6.99
AL 3	–6.15	24.58	15.58	–10.46	–8.88	–8.43	–9.72	–9.34	–9.55
AL 4	–6.67	24.03	15.05	–11.27	–9.51	–9.46	–10.54	–10.16	–10.43
AL 5	–5.38	25.36	16.36	–9.27	–7.96	–6.94	–8.53	–8.13	–8.31
Babina Mogila									
O 1	–5.22	25.53	16.52	–9.03	–7.77	–6.64	–8.29	–7.88	–8.04
O 3	–6.41	24.30	15.31	–10.87	–9.20	–8.96	–10.14	–9.76	–10.00
Drana Kokhta									
O 4	–5.28	25.47	16.46	–9.12	–7.84	–6.75	–8.38	–7.98	–8.14
O 16	–5.39	25.36	16.35	–9.28	–7.96	–6.95	–8.54	–8.15	–8.31
Ordzhonikidze									
O 9	–4.34	26.44	17.41	–7.66	–6.70	–4.91	–6.91	–6.50	–6.59
O 11	–4.98	25.78	16.76	–8.65	–7.47	–6.16	–7.91	–7.51	–7.64
O 12	–5.20	25.55	16.54	–8.99	–7.74	–6.59	–8.25	–7.85	–8.01
O 13	–5.70	25.04	16.03	–9.77	–8.34	–7.56	–9.03	–8.64	–8.82
O 14	–5.23	25.51	16.50	–9.05	–7.78	–6.66	–8.31	–7.92	–8.07
O 15	–5.55	25.19	16.19	–9.54	–8.16	–7.27	–8.79	–8.40	–8.58
Zolotaya Balka									
O 10	–6.67	24.04	15.06	–11.26	–9.50	–9.45	–10.53	–10.15	–10.41
O 5	–6.10	24.62	15.62	–10.40	–8.83	–8.36	–9.66	–9.27	–9.49
O 8	–5.98	24.75	15.75	–10.20	–8.67	–8.11	–9.46	–9.07	–9.29
O 6	–5.65	25.08	16.08	–9.69	–8.28	–7.47	–8.95	–8.56	–8.75
O 7	–5.10	25.65	16.64	–8.84	–7.62	–6.40	–8.10	–7.70	–7.85
O 2	–4.66	26.11	17.09	–8.16	–7.09	–5.53	–7.40	–7.00	–7.12

Appendix C Table 1 cont. | Results of $\delta^{18}O$ analysis for all human individuals, sorted by sample sites and a range of equations for the conversion of $\delta^{18}O_{carbonate}$ and $\delta^{18}O_{phosphate}$ to $\delta^{18}O_{water}$. Sites are arranged alphabetically according to regions. All values are given in ‰. Equations 1 to 6 are expressed vs. V-SMOW.

ID	$\delta^{18}O_{carbonate}$ (vs. V-PDB)	$\delta^{18}O_{carbonate}$ (vs. V-SMOW)	$\delta^{18}O_{phosphate}$ (vs. V-SMOW)	$\delta^{18}O_w$ (1) (Longinelli)	$\delta^{18}O_w$ (2) (Luz)	$\delta^{18}O_w$ (3) (Levinson)	$\delta^{18}O_w$ (4) (Daux)	$\delta^{18}O_w$ (5) (Pollard)	$\delta^{18}O_w$ (6) (Chenery)
Kazakhstan (cont.)									
Kazakhstan									
Berel'									
Be 2	–9.78	20.82	11.91	–16.08	–13.25	–15.53	–15.38	–15.03	–15.53
Be 3	–10.07	20.53	11.62	–16.52	–13.59	–16.08	–15.82	–15.48	–15.99
Be 4	–9.04	21.59	12.66	–14.94	–12.36	–14.09	–14.23	–13.87	–14.31
Be 5	–10.63	19.95	11.05	–17.40	–14.27	–17.19	–16.70	–16.36	–16.91
Be 8	–9.84	20.77	11.85	–16.17	–13.32	–15.64	–15.47	–15.12	–15.62
Be 11	–7.73	22.94	13.98	–12.90	–10.78	–11.52	–12.18	–11.82	–12.16
Be 12	–9.21	21.41	12.48	–15.20	–12.57	–14.42	–14.50	–14.15	–14.59
Be 13	–10.21	20.38	11.47	–16.75	–13.77	–16.37	–16.05	–15.71	–16.23
Globular Amphora Culture (Chapter 5)									
Germany									
Zauschwitz									
Z 1	–4.83	25.93	16.91	–8.43	–7.30	–5.88	–7.68	–7.28	–7.41
Z 2	–4.51	26.26	17.23	–7.93	–6.91	–5.25	–7.18	–6.78	–6.88
Z 3	–4.37	26.4	17.37	–7.72	–6.75	–4.98	–6.97	–6.57	–6.66
Z 4	–4.76	26.01	16.99	–8.31	–7.21	–5.73	–7.56	–7.16	–7.28

Applied equations:	
carbonate SMOW	Coplen et al., 1983
phosphate SMOW	Iacumin et al., 1996
$\delta^{18}O_w$ (1)	Longinelli, 1984 (as in Daux et al., 2008)
$\delta^{18}O_w$ (2)	Luz et al., 1984 (as in Daux et al., 2008)
$\delta^{18}O_w$ (3)	Levinson et al., 1987 (as in Daux et al., 2008)
$\delta^{18}O_w$ (4)	Daux et al., 2008
$\delta^{18}O_w$ (5)	Pollard et al., 2011
$\delta^{18}O_w$ (6)	Chenery et al., 2012

Appendix C Table 2 | Results of $\delta^{18}O$ analysis for all horses, sorted by sample sites and a range of equations for the conversion of $\delta^{18}O_c$ and $\delta^{18}O_p$ to $\delta^{18}O_w$. All values are given in ‰. Equations 1 to 4 are expressed vs. V-SMOW.

ID	$\delta^{18}O_{carbonate}$ (vs. V-PDB)	$\delta^{18}O_{carbonate}$ (vs. V-SMOW)	$\delta^{18}O_{phosphate}$ (vs. V-SMOW)	$\delta^{18}O_w$ (1) (S. Chillon)	$\delta^{18}O_w$ (2) (Bryant)	$\delta^{18}O_w$ (3) (D. Huertas 1)	$\delta^{18}O_w$ (4) (D. Huertas 2)
Iron Age (Scythian period)							
Kirovograd (horse)							
SU 1.1	–7.01	23.68	14.71	–10.04	–11.87	–10.53	–11.11
SU 1.2	–6.50	24.21	15.22	–9.34	–11.13	–9.82	–10.39
SU 1.3	–6.11	24.61	15.61	–8.81	–10.57	–9.28	–9.85
Berel' (horses)							
Be 1	–11.18	18.38	10.50	–15.81	–17.97	–16.38	–17.04
Be 6.1	–10.49	20.09	11.19	–14.86	–16.97	–15.42	–16.07
Be 6.2	–10.91	19.66	10.77	–15.44	–17.58	–16.00	–16.66
Be 6.3	–10.52	20.06	11.16	–14.90	–17.01	–15.46	–16.11
Be 7.1	–9.73	20.88	11.96	–13.81	–15.86	–14.35	–14.99
Be 7.2	–10.46	20.12	11.22	–14.82	–16.93	–15.38	–16.03
Be 7.3	–9.56	21.05	12.13	–13.58	–15.61	–14.11	–14.75
Be 9.1	–9.43	21.19	12.27	–13.38	–15.41	–13.92	–14.55
Be 9.2	–11.85	18.69	9.81	–16.75	–18.97	–17.33	–18.01
Be 9.3	–11.97	18.57	9.70	–16.90	–19.13	–17.49	–18.17
Be 10.1	–9.69	20.92	12.00	–13.75	–15.80	–14.29	–14.93
Be 10.2	–12.50	18.02	9.16	–17.64	–19.91	–18.24	–18.93
Be 10.3	–10.58	20.00	11.10	–14.99	–17.10	–15.54	–16.20

Applied equations:	
carbonate SMOW	Coplen et al., 1983
phosphate SMOW	Iacumin et al., 1996
$\delta^{18}O_w$ (1)	$\delta^{18}O_w = (\delta^{18}O_p - 22.04)/0.73$ (Sánchez Chillón et al., 1994)
$\delta^{18}O_w$ (2)	$\delta^{18}O_w = (\delta^{18}O_p - 22.90)/0.69$ (Bryant et al., 1994)
$\delta^{18}O_w$ (3)	$\delta^{18}O_w = (\delta^{18}O_p - 22.29)/0.72$ (Delgado Huertas et al., 1995)
$\delta^{18}O_w$ (4)	$\delta^{18}O_w = (\delta^{18}O_p - 22.60)/0.71$ (Delgado Huertas et al., 1995, wild horses)

Appendix C Table 3 | Results of $\delta^{18}O$ analysis for the cattle from Zauschwitz and a range of equations for the conversion of $\delta^{18}O_c$ and $\delta^{18}O_p$ to $\delta^{18}O_w$. All values are given in ‰. Equations 1 to 3 are expressed vs. V-SMOW.

ID	$\delta^{18}O_{carbonate}$ (vs. V-PDB)	$\delta^{18}O_{carbonate}$ (vs. V-SMOW)	$\delta^{18}O_{phosphate}$ (vs. V-SMOW)	$\delta^{18}O_{water}$ (1) (D'Angela/Longinelli 1)	$\delta^{18}O_{water}$ (2) (D'Angela/Longinelli 2)	$\delta^{18}O_{water}$ (3) (Hoppe)
Zauschwitz (cattle)						
Z 5.1	–5.03	25.72	16.71	–6.33	–8.12	–6.46
Z 5.2	–7.05	23.64	14.67	–8.87	–10.14	–9.37
Z 5.3	–7.82	22.85	13.90	–9.82	–10.90	–10.47
Z 6.1	–7.21	23.47	14.51	–9.06	–10.30	–9.60
Z 6.2	–8.43	22.22	13.27	–10.61	–11.52	–11.37
Z 6.3	–7.03	23.66	14.69	–8.84	–10.12	–9.34
Z 7.1	–6.50	24.21	15.23	–8.17	–9.58	–8.57
Z 7.2	–6.42	24.29	15.31	–8.07	–9.50	–8.46
Z 7.3	–6.07	24.65	15.66	–7.63	–9.16	–7.96

Applied equations:	
carbonate SMOW	Coplen et al. 1983
phosphate SMOW	Iacumin et al. 1996
$\delta^{18}O_w$ (1)	$\delta^{18}O_w = (\delta^{18}O_p - 21.79)/0.8$ (D'Angela/Longinelli, 1990)
$\delta^{18}O_w$ (2)	$\delta^{18}O_w = (\delta^{18}O_p - 24.91)/1.01$ (D'Angela/Longinelli, 1990 cattle New Zealand)
$\delta^{18}O_w$ (3)	$\delta^{18}O_w = (\delta^{18}O_p - 21.23)/0.7$ (Hoppe, 2006)

Appendix C Table 4 | Gender-related mean and median $\delta^{18}O_c$ values including standard deviations.

site	sex	n individuals	n samples	$\delta^{18}O_c$ median (‰ vs. V-PDB)	$\delta^{18}O_c$ mean (‰ vs. V-PDB)	± 1σ
Eneolithic and Bronze Age						
Bulgaria						
Benkovski	male ?	6 3	8 3	–4.00 –4.03	–4.21 –4.05	0.63 0.68
Boyanovo	undetermined	5	7	–4.41	–4.46	0.74
Ovchartsi	male ?	4 1	7 1	–4.00	–4.00 –5.18	0.46
Smyadovo	male female ?	4 1 2	5 1 3	–6.41 –5.56	–6.35 –5.42 –5.00	0.38 1.01
Hungary						
Hungary (all sites)	male female ?	8 2 3	9 3 5	–6.20 –4.54 –4.63	–5.86 –4.50 –4.50	0.96 0.38 0.26
Ukraine						
Kirovograd	male unknown	6 2	7 3	–5.21 –5.61	–5.18 –5.43	0.48 0.51
Nevskoe	male ?	1 4	1 4	 –5.91	–3.95 –5.87	 0.25
Peshtchanka	male female ? undetermined	4 1 1 1	6 1 2 2	–5.35	–5.93 –5.81 –5.00 –4.00	1.38 0.47 1.00
Shakhta Stepnaya	male female ?	1 2 1	1 3 2	 –4.96	–5.78 –4.00 –5.00	 0.31 0.37
Vinogradnoe	male female ?	12 3 1	14 3 2	–5.29 –4.00	–5.32 –4.00 –4.43	0.82 0.35 0.34
Russia						
Kalinovka I	male female	2 1	2 1		–6.36 –7.40	0.70
Nikolaevka III	male female ?	6 1 1	7 1 1	–6.34	–6.42 –6.66 –6.79	0.46
Olennii	male female ?	1 1 5	1 1 5	1.00 –4.93	–4.00 –5.40 –5.09	 0.39
Podlesnyi	male female	2 1	3 1	–6.53	–6.64 –6.30	1.41
Politotdel'skoe	male ?	1 2	1 2		–4.80 –5.82	 0.35
Sukhaya Termista II	male female ?	2 1 1	4 2 2	–5.04 –6.00	–5.05 –6.00 –5.22	0.63 0.66 0.16
Iron Age (Scythian period)						
Ukraine	male female ?	11 7 3	11 7 3	–5.39 –5.28 –6.10	–5.56 –5.36 –5.87	0.60 0.76 0.69
Berel' (Kazakhstan)	undetermined	6	8	–9.93	–9.00	0.66

Appendix C Table 5 | Age-related mean and median $\delta^{18}O_c$ values including standard deviations.

site	age	n individuals	n samples	$\delta^{18}O_c$ median (‰ vs. V-PDB)	$\delta^{18}O_c$ mean (‰ vs. V-PDB)	± 1σ
Eneolithic and Bronze Age						
Bulgaria						
Benkovski	infant	1	1		−4.03	
	juvenile	2	3	−4.34	−4.00	0.59
	adult	1	1		−4.20	
	mature	3	4	−3.82	−3.97	0.72
	undetermined	2	2	−4.00	−4.00	0.96
Boyanovo	undetermined	5	7	−4.41	−4.46	0.74
Ovchartsi	juvenile	1	1		−4.49	
	adult	2	4	−3.96	−4.00	0.43
	mature	1	2		−4.00	0.70
	undetermined	1	1		−5.18	
Smyadovo	infant	1	1		−5.62	
	juvenile	1	2	−4.70	−4.70	1.22
	adult	6	6	−6.26	−6.19	0.51
Hungary						
Hungary (all sites)	infant	1	2		−4.24	
	juvenile	2	3	−4.63	−4.53	0.39
	adult	7	8	−5.00	−5.33	0.75
	mature	3	4	−6.51	−6.01	1.36
Ukraine						
Kirovograd	infant	1	2		−5.34	0.69
	juvenile	1	1		−5.61	
	adult	3	3		−5.32	0.15
	mature	3	4	−4.72	−5.08	0.64
Nevskoe	juvenile	1	1		−3.95	
	adult	4	4	−5.91	−5.87	0.25
Peshtchanka	juvenile	1	2		−5.00	0.47
	adult	4	6	−5.40	−5.95	1.38
	mature	1	1		−5.71	
	undetermined	1	2		−4.00	1.00
Shakhta Stepnaya	adult	3	4	−5.00	−5.15	0.49
	mature	1	2		−5.00	0.37
Vinogradnoe	juvenile	1	2		−4.43	0.34
	adult	11	13	−5.45	−5.54	0.78
	mature	4	6	−4.59	−4.79	0.61
Russia						
Kalinovka I	mature	2	2		−6.36	0.70
	senile	1	1		−7.40	
Nikolaevka III	infant	1	1		−5.77	
	juvenile	1	1		−6.79	
	adult	1	1		−6.87	
	mature	5	6	−6.35	−6.51	0.34
Olennii	infant	4	4	−5.13	−5.19	0.36
	adult	3	3	−4.00	−5.99	0.38

Appendix C Table 5 cont. | Age-related mean and median $\delta^{18}O_c$ values including standard deviations.

site	age	n individuals	n samples	$\delta^{18}O_c$ median (‰ vs. V-PDB)	$\delta^{18}O_c$ mean (‰ vs. V-PDB)	± 1σ
Podlesnyi	juvenile	1	1		–6.30	
	adult	1	2		–7.32	1.00
	mature	1	1		–5.29	
Politotdel'skoe	infant	1	1		–5.58	
	adult	1	1		–6.07	
	mature	1	1		–4.80	
Sukhaya Termista II	adult	2	4	–5.59	–5.54	0.80
	mature	1	2		–5.00	0.75
	undetermined	1	2		–5.22	0.16
Iron Age (Scythian period)						
Ukraine	juvenile	3	3	–6.10	–5.93	0.59
	adult	7	7	–5.55	–5.58	0.78
	mature	10	10	–5.31	–5.44	
	undetermined	1	1		–5.00	
Berel' (Kazakhstan)	undetermined	6	8	–9.81	–9.56	0.90

Appendix C Table 6 | Chronological groups: Mean and median $\delta^{18}O_c$ values including standard deviations.

site	cultural period	n individuals	n samples	$\delta^{18}O_c$ median (‰ vs. V-PDB)	$\delta^{18}O_c$ mean (‰ vs. V-PDB)	± 1σ
Eneolithic and Bronze Age						
Bulgaria						
Benkovski	Early Bronze Age/Yamnaya	9	11	–4.08	–4.16	0.61
Boyanovo	Early Bronze Age/Yamnaya Middle Bronze Age	4 1	5 2	–4.41	–4.00 –4.00	0.81 0.78
Ovchartsi	Early Bronze Age/Yamnaya	5	8	–4.25	–4.24	0.57
Smyadovo	Eneolithic/Copper Age Early Bronze Age/Yamnaya	7 1	8 1	–5.97	–5.85 –5.42	0.92
Hungary						
Hungary (all sites)	Eneolithic/Copper Age Early Bronze Age/Yamnaya	1 12	2 15	 –4.87	–4.49 –5.32	0.54 1.01
Ukraine						
Kirovograd	Early Bronze Age/Yamnaya Middle Bronze Age/Catacomb culture	7 1	8 2	–5.52	–5.57 –4.72	0.77 0.01
Nevskoe	Middle Bronze Age/Catacomb culture	5	5	–5.81	–5.49	0.89
Peshtchanka	Eneolithic/Copper Age Early Bronze Age/Yamnaya Middle Bronze Age/Catacomb culture	4 2 1	5 4 2	–5.81 –4.88	–6.35 –4.96 –4.99	1.25 0.34 1.00
Shakhta Stepnaya	Early Bronze Age/Yamnaya Middle Bronze Age/Catacomb culture	2 2	3 3	–5.38 –4.96	–5.34 –4.00	0.47 0.31
Vinogradnoe	Eneolithic/Copper Age Early Bronze Age/Yamnaya Middle Bronze Age/Catacomb culture	2 4 10	2 6 13	–5.45 –4.00 –5.00	–5.08 –5.00 –5.23	0.70 0.80 0.84
Russia						
Olennii	Novotitarovskaya	7	7	–4.93	–5.00	0.35
Sukhaya Termista II	Middle Bronze Age/Catacomb culture	4	8	–5.43	–5.33	0.64
Volga (all sites)	Poltavka	17	19	–6.35	–6.42	0.78
Iron Age (Scythian period)						
Ukraine	Scythian	21	21	–5.39	–5.54	0.66
Berel' (Kazakhstan)	Scythian	6	8	–9.81	–9.56	0.90

Appendix D

Appendix D Table 1a | Human bone collagen samples with archaeological identification and results of triplicate $\delta^{13}C$ and $\delta^{15}N$ measurements. % C and % N were not given in the data summary provided by the RLAHA, University of Oxford.

ID	site	kurgan	burial	item	$\delta^{13}C$ (‰) (vs. V-PDB)	S.E.	$\delta^{15}N$ (‰) (vs. AIR)	S.E.	C/N	% collagen
Eneolithic and Bronze Age										
Bulgaria										
CG 80	Benkovski	2	1	human bone	–19.0	0.1	9.6	< 0.1	3.3	3.9
CG 81	Benkovski	2	2	human bone	–18.0	< 0.1	9.9	0.1	3.2	8.6
CG 82	Benkovski	2	5	humane bone	–17.5	< 0.1	9.5	< 0.1	3.2	11.2
CG 56	Boyanovo		14 (sk. 1)	human bone	–17.3	0.1	10.7	0.1	3.3	5.7
CG 57	Boyanovo		14 (sk. 2)	human bone	–17.0	0.1	10.1	0.1	3.3	3.2
CG 58	Boyanovo		5	human bone	–16.7	0.1	10.5	< 0.1	3.3	9.0
CG 59	Boyanovo		6	human bone	–17.1	0.3	10.9	0.1	3.4	1.7
CG 60	Boyanovo		4	human bone	–17.2	0.1	9.7	< 0.1	3.3	9.2
CG 48	Smyadovo		18	human bone	–19.7	0.1	10.2	0.4	3.3	4.0
CG 49	Smyadovo		22	human bone	–20.6	< 0.1	9.3	0.1	3.3	4.1
CG 50	Smyadovo		26	human bone	–20.0	0.1	9.0	0.7	3.3	5.9
CG 51	Smyadovo		24a	human bone	–20.4	< 0.1	8.4	0.2	3.2	10.8
CG 52	Smyadovo		24b	human bone	–20.0	0.1	9.0	0.1	3.3	8.0
CG 75	Smyadovo		11	human bone	–20.3	< 0.1	9.2	0.1	3.2	8.1
CG 76	Smyadovo		8	human bone	–20.5	0.1	8.0	0.1	3.3	9.9
CG 77	Smyadovo		13	human bone	–20.6	< 0.1	8.0	< 0.1	3.2	7.9
CG 78	Smyadovo		10	human bone	–20.3	0.1	9.6	0.1	3.3	7.8
CG 79	Smyadovo		6	human bone	–20.0	0.1	9.2	0.1	3.2	7.6
Ukraine										
CG 12	Kirovograd	1	5	human bone	–19.0	0.2	11.0	0.3	3.2	4.0
CG 83	Kirovograd	1	5	human bone	–19.2	< 0.1	11.0	< 0.1	3.2	22.7
CG 7	Kirovograd	1	8	human bone	–19.0	< 0.1	12.5	0.1	3.4	8.2
CG 8	Kirovograd	1	10 (child)	human bone	–19.0	0.1	10.9	0.1	3.2	7.7
CG 89	Kirovograd	1	10 (child)	human tooth (M1)	–19.3	< 0.1	13.0	0.1	3.2	7.5
CG 92	Kirovograd	1	10 (child)	human tooth (M2)	–19.5	< 0.1	10.7	0.1	3.4	2.7
CG 14	Kirovograd	1	13	human bone	–19.3	0.2	11.0	1.6	3.2	15.1
CG 84	Kirovograd	1	14	human bone	–19.0	0.1	12.4	0.1	3.2	13.2
CG 10	Kirovograd	1	16	human bone	–19.3	< 0.1	10.1	0.4	3.2	15.9
CG 11	Kirovograd	1	20	human bone	–19.4	0.1	11.5	0.3	3.2	6.1
CG 91	Kirovograd	1	20	human tooth (M2)	–19.0	0.1	11.3	0.1	3.2	15.5
CG 90	Kirovograd	1	20	human tooth (M3)	–19.3	< 0.1	11.5	0.1	3.2	15.8
CG 13	Kirovograd	1	24	human bone	–19.0	< 0.1	11.0	0.2	3.2	15.5
CG 1	Peshtchanka	1	6	human bone	–18.8	0.1	12.0	0.1	3.2	12.2
CG 2	Peshtchanka	1	15	human bone	–19.0	0.2	11.0	0.1	3.2	9.3
CG 4	Peshtchanka	1	10	human bone	–18.2	0.2	13.0	0.4	3.2	11.1
CG 5	Peshtchanka	1	11	human bone	–18.8	< 0.1	11.7	0.2	3.2	5.5
CG 93	Peshtchanka	1	14	human tooth (M1)	–17.2	< 0.1	15.9	0.1	3.4	1.8
CG 94	Peshtchanka	1	14	human tooth (M2)	–17.5	< 0.1	14.3	0.1	3.2	11.0
CG 95	Peshtchanka	1	6	human tooth (M1)	–18.5	< 0.1	12.2	0.1	3.2	14.3
CG 96	Peshtchanka	1	6	human tooth (M3)	–18.8	< 0.1	12.3	< 0.1	3.2	6.7
CG 86	Sh. Stepnaya	4	11	human bone	–18.9	< 0.1	11.8	0.3	3.3	11.6
CG 88	Sh. Stepnaya	4	10	human bone	–18.0	< 0.1	12.5	< 0.1	3.3	23.0
CG 15	Vinogradnoe	3	15	human bone	–19.0	0.3	13.4	0.3	3.2	6.6
CG 16	Vinogradnoe	3	25	human bone	–18.5	0.1	12.9	0.3	3.2	6.7
CG 17	Vinogradnoe	24	15 (sk. 2)	human bone	–17.9	0.1	13.4	0.3	3.2	9.0
CG 18	Vinogradnoe	24	15 (sk. 1)	human bone	–18.0	0.1	13.1	0.1	3.2	9.9
CG 19	Vinogradnoe	24	34 (sk. 1)	human bone	–17.8	0.1	12.9	0.1	3.2	11.8
CG 20	Vinogradnoe	24	31	human bone	–18.8	0.1	12.4	0.2	3.2	13.6
CG 21	Vinogradnoe	24	34 (sk. 2)	human bone	–18.0	0.1	14.0	0.1	3.2	1.3

Appendix D Table 1a cont. | Human bone collagen samples with archaeological identification and results of triplicate $\delta^{13}C$ and $\delta^{15}N$ measurements. % C and % N were not given in the data summary provided by the RLAHA, University of Oxford.

ID	site	kurgan	burial	item	$\delta^{13}C$ (‰) (vs. V-PDB)	S.E.	$\delta^{15}N$ (‰) (vs. AIR)	S.E.	C/N	% collagen
CG 22	Vinogradnoe	24	32	human bone	–19.2	< 0.1	12.1	0.2	3.2	10.2
CG 23	Vinogradnoe	24	17	human bone	–18.9	0.1	12.1	0.1	3.2	17.2
CG 24	Vinogradnoe	24	8 (sk. 2)	human bone	–18.5	< 0.1	12.4	< 0.1	3.2	13.1
CG 25	Vinogradnoe	24	22	human bone	–18.2	0.1	12.8	0.1	3.2	8.6
CG 26	Vinogradnoe	24	19	human bone	–18.0	0.1	13.1	0.1	3.2	15.1
Russia										
CG 45	Olennii	3	14a	human bone	–18.8	0.1	12.0	< 0.1	3.2	14.9
CG 46	Olennii	2	25b	human bone	–19.5	0.1	11.5	0.1	3.2	17.6
CG 47	Olennii	2	35a	human bone	–19.6	< 0.1	13.1	0.2	3.3	8.7

Appendix D Table 1b | Faunal bone collagen samples with archaeological identification and the $\delta^{13}C$ and $\delta^{15}N$ mean of triplicate measurement for each sample, reported relative to standard V-PDB ($\delta^{13}C$) and AIR ($\delta^{15}N$). % C and % N were not given in the data summary provided by the RLAHA, University of Oxford.

ID	site	kurgan	burial	bone	$\delta^{13}C$ (‰) (vs. V-PDB)	S.E.	$\delta^{15}N$ (‰) (vs. AIR)	S.E.	C/N	% collagen
Eneolithic and Bronze Age										
Bulgaria										
CG 70	Ovchartsi	Big Tumulus	10	animal	–19.0	< 0.1	12.5	0.1	3.4	8.0
Ukraine										
CG 55	Kirovograd	1	15 (KMK)	sheep/goat	–19.5	0.1	10.6	0.1	3.4	4.2
CG 54	Kirovograd	1	16	sheep/goat	–18.7	< 0.1	7.4	0.1	3.2	15.2
CG 98	Kirovograd	1	16	sheep/goat	–18.7	< 0.1	7.2	0.1	3.2	17.0
CG 63	Novozvanovka II	1		animal	–20.8	< 0.1	4.0	< 0.1	3.2	8.0
CG 64	Mayaki			cattle	–18.7	< 0.1	6.7	< 0.1	3.3	5.2

Appendix D Table 2 | Failed stable isotope measurements of human and faunal bone collagen samples. % C and % N were not given in the data summary provided by the RLAHA, University of Oxford.

ID	site	kurgan	burial	specimen	% collagen
CG 9	Kirovograd	1	10, adult	human	0.8
CG 3	Peshtchanka	1	7	human	0.2
CG 6	Peshtchanka	1	14	human	0.3
CG 85	Shakhta Stepnaya	2	7	human	0.9
CG 87	Shakhta Stepnaya	2	4	human	1.5
CG 97	Shakhta Stepnaya	4	10	animal	0.7

Appendix D Table 3 | Total sample size of human bone of each site, mean stable carbon ($\delta^{13}C$), nitrogen ($\delta^{15}N$) isotopic values, standard deviations and ranges per site.

site	n bone samples	$\delta^{13}C$ mean (‰) (vs. V-PDB)	± 1σ	$\delta^{13}C$ range (‰) (vs. V-PDB)	$\delta^{15}N$ mean (‰) (vs. AIR)	± 1σ	$\delta^{15}N$ range (‰) (vs. AIR)
Eneolithic and Bronze Age							
Bulgaria							
Benkovski	3	–18.3	0.8	1.5	9.0	0.2	0.4
Boyanovo	5	–17.0	0.2	0.5	10.4	0.5	1.3
Smyadovo	10	–10.3	0.3	1.0	9.1	0.6	1.9
Ukraine							
Kirovograd	9	–19.3	0.2	0.5	11.3	0.8	2.5
Peshtchanka	4	–18.7	0.4	0.8	11.9	0.9	2.1
Sh. Stepnaya	2	–19.0	< 0.1	0.1	12.2	0.5	0.7
Vinogradnoe	12	–18.5	0.5	1.7	12.9	0.6	1.9
Russia							
Olennii	3	–19.3	0.4	0.8	12.2	0.8	1.6

Appendix D Table 4 | Average $\delta^{13}C$ and $\delta^{15}N$ for the different time periods in the West and North Pontic.

site	$\delta^{13}C$ mean (‰, vs. V-PDB) ± 1σ				$\delta^{15}N$ mean (‰, vs. AIR) ± 1σ			
	Eneolithic	**Early Bronze Age**	**Middle Bronze Age**		**Eneolithic**	**Early Bronze Age**	**Middle Bronze Age**	
Eneolithic and Bronze Age								
Bulgaria								
Benkovski		–18.3 ± 0.8				9.7 ± 0.2		
Boyanovo		–17.0 ± 0.2	–17.2			10.5 ± 0.4	9.7	
Smyadovo	–20.4 ± 0.2				9.1 ± 0.5			
	Eneolithic	**Yamnaya**	**Early Catacomb**	**Developed Catacomb**	**Eneolithic**	**Yamnaya**	**Early Catacomb**	**Developed Catacomb**
Eneolithic and Bronze Age								
Ukraine								
Kirovograd		–19.2 ± 0.2		–19.3		11.4 ± 0.9		11.0
Peshtchanka	–18.8	–18.7 ± 0.4			12.0	11.9 ± 1.0		
Sh. Stepnaya		–18.9		–18.0		11.8		12.5
Vinogradnoe	–19.0	–18.6 ± 0.2	–18.1 ± 0.2	–19.1 ± 0.2	13.4	12.6 ± 0.3	13.2 ± 0.4	12.1 ± 0.0

Appendix D Table 5 | Average $\delta^{13}C$ and $\delta^{15}N$ for males, females, non-sex-determined skeletons and skeletons with undetermined sex.

site	n sex ?	$\delta^{13}C$ mean (‰, vs. V-PDB) ± 1σ	$\delta^{15}N$ mean (‰, vs. AIR) ± 1σ	n female	$\delta^{13}C$ mean (‰, vs. V-PDB) ± 1σ	$\delta^{15}N$ mean (‰, vs. AIR) ± 1σ	n male	$\delta^{13}C$ mean (‰, vs. V-PDB) ± 1σ	$\delta^{15}N$ mean (‰, vs. AIR) ± 1σ
Eneolithic and Bronze Age									
Ukraine									
Kirovograd	3	–19.2 ± 0.2	11.5 ± 0.9	0			6	–19.3 ± 0.1	11.2 ± 0.8
Peshtchanka	1	–18.8	11.7	1	–19.0	11.0	2	–18.5 ± 0.5	12.5 ± 0.7
Sh. Stepnaya	1	–18.9	11.8	1	–18	12.5	0		
Vinogradnoe	1	–18.5	12.4	2	–17.8 ± 0.1	13.2 ± 0.4	9	–18.6 ± 0.5	12.1 ± 0.6
Olennii	3	–19.3 ± 0.4	12. ± 0.8	0			0		

Appendix D Table 6 | Average $\delta^{13}C$ and $\delta^{15}N$ for infants, juveniles and adults (*adultus* and *maturus*).

site	n infants	$\delta^{13}C$ mean (‰, vs. V-PDB) ± 1σ	$\delta^{15}N$ mean (‰, vs. AIR) ± 1σ	n juvenile	$\delta^{13}C$ mean (‰, vs. V-PDB) ± 1σ	$\delta^{15}N$ mean (‰, vs. AIR) ± 1σ	n adult	$\delta^{13}C$ mean (‰, vs. V-PDB) ± 1σ	$\delta^{15}N$ mean (‰, vs. AIR) ± 1σ
Eneolithic and Bronze Age									
Ukraine									
Kirovograd	1	–19.0	10.9	1	–19.0	11.0	6	–19.3 ± 0.1	11.2 ± 0.1
Peshtchanka	1	–18.8	11.7				3	–18.7 ± 0.1	12.0 ± 0.3
Sh. Stepnaya							2	–19.0 ± 0.0	12.2 ± 0.5
Vinogradnoe				2	–18.4 ± 0.0	12.2 ± 0.5	10	–18.5 ± 0.6	12.9 ± 0.6
Olennii	2	–19.6 ± 0.1	12.3 ± 1.1				1	–18.8	12.0